

JOURNAL OF THE ROYAL SOCIETY OF NEW ZEALAND

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THE ROYAL SOCIETY OF NEW ZEALAND

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Publications

Volume 1 of the annual *Transactions and Proceedings of the New Zealand Institute* was published in 1869 (reprinted in revised form, 1875). The *Transactions* were published in quarterly parts from Volume 58 (1927-28) to Volume 88 (1960-61). A new volume numbering system and a division into sections (Zoology, Botany, Geology, and General) was instituted in 1961. In 1968, the number of sections was reduced to three (Biological Sciences, Earth Sciences, and General). Publication in this form, in which each paper was issued separately, was concluded at the beginning of 1971. This *Journal* is the successor to the *Transactions* of the Society and its predecessor, the New Zealand Institute. An author and title index to the complete run of the *Transactions* is available from the Society's offices (\$10; \$5 for members of affiliated societies).

The *Proceedings* of the Society (formerly included with the *Transactions*) have been published separately from Volume 85 (1958), the latest number being Volume 109 (for 1981), issued in 1982. They include a full account of the Society's activities, names and addresses of fellows and honorary members, personnel and reports of committees, the Council's annual report, annual reports of member bodies, details of the Society's medals and prizes with lists of medallists and prize-winners, trust and other funds, research grants and reports of grant recipients, occasional special articles, and obituaries. They also list the current honorary and paid officers of the Society. The Royal Society of New Zealand Act (1965), amending the 1933 Act, and the Rules adopted under the authority of the act were last published in the *Proceedings* for 1968-69; a current set of rules is available from the Society's offices.

Bulletins of the Society consist of works of scientific research that are considered unsuitable, because of size or content, for publication in the *Journal*. They are published at irregular intervals, subject to the approval of the council in each instance.

The Society also publishes a *Miscellaneous Series*, which in general includes reports of special committees established by the Society's council. These are also published at irregular intervals. This series also includes some conference proceedings and related material.

All members of the affiliated member bodies of the Society receive a *Newsletter* about four times a year.

Selected publications available from the Society are described on the inside back cover of this journal.

Numerical assessment of erosion from old and recent photographs: A case study from a section of Highway 73, Canterbury, New Zealand

I. E. Whitehouse*

Nineteenth-century photographs from the Broken River and Porters Pass area along State Highway 73 (Christchurch to Arthur's Pass) are compared with recent photographs of the same sites. On four pairs, small increases and decreases in vegetation cover can be detected; these were assessed by use of a grid overlay. Photo-pairs showed that most of the erosion scars evident today were present early in the period of European settlement. If farm management in the last 130 years had led to a consistent trend of change in area of bare ground and vegetation cover, a consistent improvement or deterioration might be expected, but no marked or consistent pattern was observed.

INTRODUCTION

It is difficult to get objective information on erosion changes in the South Island high country during the last 130 years, although this is needed to assess the effect of management practices on vegetation cover. Since 1947, the Catchment Authorities (Dick, 1978; Ramsay, 1979) and Forest Service (Evans, 1969; McLennan, 1974) have carried out quantitative assessments of vegetation by point and line intercept sampling and by analysis of repeated stereo colour slides. This has provided a measure of change in the area and type of vegetation cover. Dick (1978) extended some of these results to examine changes since European settlement and the effect of management on vegetation cover and erosion. The short-term nature of these measurements contrasts with the many years of management, so it seems likely that any inferences drawn must be very tentative.

Illustrations in Relf (1958: 132-135), Campbell (1966: 4, 7, 10), McLeod (1967: 13-23), Moore (1976), and Burrows (1977: 176-177) show the value of photographic comparisons for indicating the degree of change in ground cover in the South Island high country. The first part of this paper tests a method for a quantitative comparison of changes in vegetation cover with respect to bare ground on pre-1900 and recent photographs. Localities studied are between Porters Pass and the Broken River Basin, Canterbury. The second part of the paper concerns the interpretation of the results of applying this method.

GENERAL METHOD

Copies of old photographs were obtained from museum, library, and private collections; only those that could be dated to within ten years were used. Undated photographs taken by identified photographers were dated from biographical information in Knight (1971) and Turner (1970). Photo librarians at the Canterbury Museum, Alexander Turnbull Library, and Hocken Library were able to date other photographs.

New photographs were taken, as close as possible to the site of the older ones, although in some instances road realignment or growth of trees or scrub made exact duplication impossible. No attempt was made to retouch blemishes on old photographs.

Six pairs of photographs, from locations identified in Figure 1, are shown in Figures 2-7.

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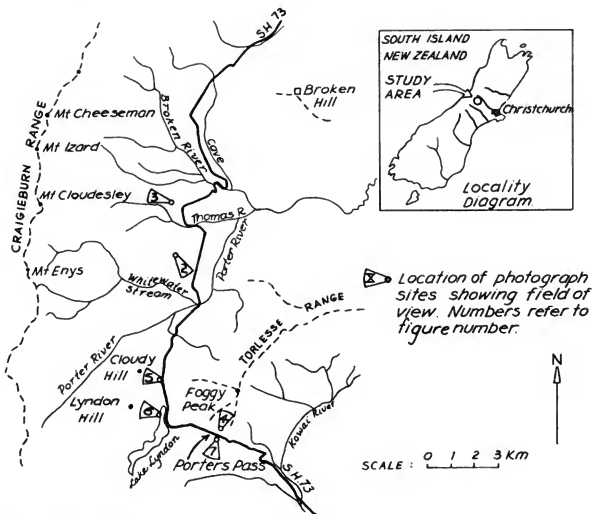


Fig. 1—Locality map.

SAMPLE METHOD TRIALS

Photograph pairs were compared visually for changes in proportion of bare ground to vegetation, and for changes in erosion features. No attempt was made to assess changes in vegetation composition. Two methods were used to assess ground changes.

A combined count of changes was made by placing either a set of random points or a 1-cm point grid over the older photograph of each pair. For each of the 100-150 points the corresponding position on the paired photograph was located by consideration of relative position on slope and of rock exposures. Points on the photographs probably correspond with points on the ground within a metre of each other. Comparison of cover around these points was made in order to assess the extent of change.

Each point examined was assigned a category in accordance with an observer's impression of changes in the immediate vicinity of that point. There were four categories:

- (i) vegetation cover to bare ground;
- (ii) no change;
- (iii) bare ground to vegetation cover; and
- (iv) change uncertain.

Replacement of tussock grassland by scrub was considered "no change."

Table 1 details two observers' examination of Figure 5 using the random-point overlay and the 1-cm point grid. Results from each observer showed no variation between the two grids; therefore, the 1-cm grid was adopted for the balance of the study, as it was easier to locate points on the paired photograph with this grid. The results from the two observers were compared by using Student's *t* test; a small, but significant, difference between the two observers at the 90% confidence level was noted.



Fig 2—Ghost Stream, Torlesse Range, from behind Castle Hill homestead, Castle Hill peak on right. Erosion features and outlines of small forest patches do not appear to have changed. A: 1880's; B: 1977.

Observer bias is highlighted in the results obtained from different observers' using (on Figure 4) the 1-cm point grid (Table 2). All observers agreed that there had been little net change; however, there was variation in the magnitude of change recorded. The results shown in Tables 1 and 2 indicate that for consistent results it is important to use the same observer on all photo-pairs. While this method is not necessarily a good measure of the actual change, it is a good measure of the direction of change. It is noteworthy that an experienced observer provided estimates close to that of the mean of the less experienced.

Separate counts of changes in the proportion of bare ground to cover were made by placing 0.5 cm grids over both photographs and noting the presence of either vegetation or bare ground. When this procedure was carried out on Figure 4 by different observers,



Fig. 3—Craigieburn Range from behind the old Castle Hill homestead, Mt Cloudsley on left. The older photograph is one of the earliest available, taken about ten years after the first European burning. The eroding area on the left centre slope has increased. A: 1868; B: 1978.

TABLE 1: Variation between random-point and one-centimetre point grids on Figure 5.

| | Trial | % Increase bare ground | % Decrease bare ground | % No change | % Uncertain |
|----------------|-------|---------------------------|---------------------------|----------------|----------------|
| OBSERVER 1 | | | | | |
| Random grid | 1 | 2.5 | 26 | 71.5 | - |
| | 2 | 4.5 | 25.5 | 70 | - |
| | 3 | 2 | 30 | 68 | - |
| Mean | | 3.0 | 27.2 | 69.8 | |
| S.D. | | 1.6 | 3.0 | 2.2 | |
| 1-cm grid | 1 | 2.5 | 26.5 | 71 | - |
| | 2 | 4 | 26 | 69 | 1 |
| | 3 | 3 | 25 | 72 | 1 |
| Mean | | 3.1 | 25.8 | 70.6 | |
| S.D. | | 1.0 | 0.9 | 1.9 | |
| OBSERVER 2 | | | | | |
| Random grid | 1 | 4 | 21 | 75 | - |
| | 2 | 3 | 19 | 78 | - |
| Mean | | 3.5 | 20 | 76.5 | |
| 1-cm grid | 1 | 6 | 17 | 77 | |
| | 2 | 4 | 19 | 77 | |
| Mean | | 5 | 18 | 77 | |

TABLE 2: Variation between observers using one-centimetre point grid overlay on Figure 4.

| Observer | % Decrease in bare ground area | % Increase in bare ground area | % No change | % Uncertain |
|----------|-----------------------------------|-----------------------------------|----------------|----------------|
| 1 | 9 | 9 | 80 | 2 |
| 2 | 17 | 9 | 72 | 2 |
| 3 | 14 | 10 | 73 | 2 |
| 4 | 15 | 11 | 73 | 1 |
| 5 | 13 | 17 | 67 | 3 |
| 6 | 20 | 15 | 64 | 1 |
| Mean | 14.7 | 11.8 | 71.5 | 1.8 |
| S.D. | 4.1 | 3.7 | 6.1 | 0.8 |

little observer bias was exhibited (Table 3). This method provided a quick assessment of net change only. Comparison of Tables 2 and 3 shows that no net change has occurred on Figure 4; however, careful visual examination reveals that this lack of net change is a result of moderate but equal changes from vegetation to bare ground and bare ground to vegetation.

APPLICATION OF THE METHOD AND INTERPRETATION OF THE RESULTS

The method described above was applied to the best of the detailed photo-pairs (Figs. 4, 5, 6, 7). Point counts of change and proportion of bare ground to cover are listed in Tables 4 and 5. Figure 4 shows little net change, Figures 6 and 7, decrease in bare ground; Figure 5 shows increases in bare ground and an increase in the size and number of gullies. In some pairs (especially Figures 4 and 7), the same or very similar plants or groups of plants can be seen on both the old and the recent photographs.

Most of the landscape views show little change in the gross distribution of bare, eroding areas in the last one hundred years. Areas of scree have remained fairly constant (Fig. 2), and slopes prone to gullying have continued to erode (McLeod, 1967: 23; Whitehouse, 1978, p L. III). An exception to this pattern is shown in Figure 3, where there is considerable increase in bare ground on some slopes.

TABLE 3: Variation between observers assessing bare ground and vegetation cover on Figure 4 using 0.5-cm dot grid overlaid randomly on each photograph.

| Observer | Date of photograph | % Bare ground | % Vegetation cover |
|----------|--------------------|---------------|--------------------|
| 1 | 1890 | 21 | 79 |
| | 1978 | 19 | 81 |
| 2 | 1890 | 24 | 76 |
| | 1978 | 24 | 76 |
| 3 | 1890 | 20 | 80 |
| | 1978 | 24 | 76 |
| 4 | 1890 | 23 | 77 |
| | 1978 | 25 | 75 |
| Mean | (1890) | 22 | 78 |
| S.D. | | 2.1 | 2.1 |
| Mean | (1978) | 23 | 77 |
| S.D. | | 3.1 | 3.1 |

TABLE 4: Percent change in area of bare ground from comparison of one-centimetre point grid overlay.

| Figure | Decrease | Increase | No change | Uncertain |
|--------|----------|----------|-----------|-----------|
| 4 | 9 | 9 | 80 | 2 |
| 5 | 4 | 26 | 69 | - |
| 6 | 28 | 4 | 63 | 5 |
| 7 | 27 | 6 | 65 | 2 |

TABLE 5: Percent bare ground and vegetation from 0.5-cm grid overlaid on old and recent photographs.

| Figure | Date | Vegetation | Bare ground | Number of points |
|--------|------|------------|-------------|------------------|
| 4 | 1978 | 81 | 19 | 560 |
| | 1890 | 79 | 21 | |
| 5 | 1978 | 68 | 32 | 520 |
| | 1890 | 80.5 | 19.5 | |
| 6 | 1979 | 84 | 16 | 260 |
| | 1889 | 71 | 29 | |
| 7 | 1978 | 53 | 47 | 640 |
| | 1890 | 43 | 57 | |

Much of the area shown in the photographs has been extensively grazed and was repeatedly burnt between the late 1850's and the 1920's (McLeod and McLeod, 1977). Sheep numbers were very high from the 1870's to the 1910's, reaching a maximum in 1895 (Hayward, 1967). Grazing and other management practices over the last century appear, thus, to have had little effect on the gross erosion features of the area. All the detailed photo-pairs are of slopes within five kilometres of each other (Fig. 1).

Small changes in area of bare ground or vegetation cover can be detected on these photo-pairs (Figs. 4-7), but the changes are very variable. Different photo-pairs show increase, decrease, or no change in area of bare ground; within a single pair, different areas show increase and decrease in bare ground. This variation could be random, or the result of different intensity of farm practices, or the result of specific site differences. It might be expected that there would have been an increase in bare ground till about 1920, during and after the period of high stock numbers and frequent burning, and a decrease since about 1930, after which stock numbers were lower and burning controlled.



Fig. 4—Snowgrass- and *Dracophyllum*-covered slopes north of Porters Pass. There has been local increase in both vegetation and bare ground, but no net change. A: 1890's; B: 1978.



Fig 5—Cloudy Hill, west side of State Highway 73 near Lake Lyndon. Increase in erosion and scrub is apparent. A: 1890, B: 1978.



Fig. 6—Slopes of Lyndon Hill from northern end of Lake Lyndon. There has been an increase in vegetation, particularly matagouri scrub. A: 1889; B: 1979.



Fig. 7—Snowgrass and matagouri scrub-covered slope south of Porters Pass. Some increase in vegetation cover is apparent. A. 1890; B. 1978.

However, from analysis of line transects in the area, Dick (1978) indicates that bare ground increased from 1947 to 1963. He suggests that this continuing increase is the consequence of past land management. If management had led to a consistent trend of change in areas of vegetation cover and bare ground in this region, it might be expected that Figures 4 through 7 would all show either marked improvement or marked deterioration. This is not observed; rather, there is a wide variability within the photographed areas, demonstrating a lack of consistent trend.

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Old photographs used in Figures 2, 3, 5, 6, and 7 are printed by permission of the Canterbury Museum; Figures 2 and 5 are attributed to Burton Brothers, Figures 3, to E. P. Sealy. Figure 4, by J. R. Morris, is printed by permission of the Hocken Library. (Modern photographs were taken by the author.)

REFERENCES

- Burrows, C. J. 1977. Vegetation in the Cass District and its Ecology. In C. J. Burrows (Ed.), *Cass. Department of Botany, University of Canterbury*. Pp. 173-184.
- Campbell, D. A. 1966. Miracle of management. *Soil and Water* 2(3): 4-12.
- Dick, R. D. 1978. Towards greater understanding of the Waimakariri mountain tussock grasslands. *Proceedings of the Conference on Erosion Assessment and Control in New Zealand*. N.Z. Association of Soil Conservators. Pp. 43-61.
- Evans, G. R. 1969. The alpine and upper montane grasslands of the Harper and Avoca River catchments. *Protection Forestry Report* 66.
- Hayward, J. A. 1967. The Waimakariri catchment. *Tussock Grasslands and Mountain Land Institute Special Publication* 5.
- Knight, H. 1971. Photography in New Zealand. John McIndoe: Dunedin.
- McLennan, M. J. 1974. The alpine grasslands in the Upper Waimakariri Catchment from 1961 to 1972. *Protection Forestry Report* 130.
- McLeod, D. 1967. The high country then and now. *Tussock Grasslands and Mountain Lands Review* 13: 18-23.
- McLeod, D., and I. McLeod. 1977. The farming endeavour. In C. J. Burrows (Ed.), *Cass. Department of Botany, University of Canterbury*. Pp. 37-52.
- Moore, L. B. 1976. The changing vegetation of Molesworth Station, New Zealand. *N.Z. Department of Scientific and Industrial Research Bulletin* 217.
- Ramsay, J. W. 1979. An analysis of trends in snow tussock grassland over the period 1958-1973 — "Dunstan Burn", St Bathans. *Otago Catchment Board Soil Conservation Report* 1979/62.
- Relf, D. 1958. A century of human influence on high country vegetation. *N.Z. Geographer* 14(2): 131-146.
- Turner, J. B. 1970. *Nineteenth-century New Zealand Photographers*. Govett-Brewster Art Gallery: New Plymouth.
- Whitehouse, I. E. 1978. A century of erosion and recovery. *Soil and Water* 14(5): 10-14.

The centrolophid fishes of New Zealand (Pisces : Stromateoidei)

R. M. McDowall*

A review of the New Zealand centrolophid fishes shows the following species to be present:

Hyperoglyphe antarctica (Carmichael): a deep-water benthic species widespread in the southern oceans; *Seriola punctata* (Forster, in Bloch and Schneider): shelf edge and deeper waters, widespread from Australia to South America; *S. brama* (Günther): largely in southern coastal waters, present also in southern Australia; *S. caerulea* Guichenot (= *S. tinro* Gavrillov): southern, deeper, offshore waters, from Tasmania to Patagonian South America; *S. labyrinthica* (McAllister and Randall): one specimen known from northern New Zealand shores, also other Pacific Islands from Lord Howe to Easter and Juan Fernandez; *Centrolophus niger* (Gmelin): not uncommon in deeper, offshore waters, an almost cosmopolitan species; *Schedophilus huttoni* (Waite): very rare, mostly from beach cast specimens, presumably a deep-water species, present also in the South Atlantic and off eastern Australia; *S. maculatus* Günther: a rare deep-water species known largely from juveniles, south Pacific, possibly southern circum polar; *Ichthyos australis* Haedrich: a rare deep-water species in southern New Zealand, also off Tasmania, south Atlantic and sub-Antarctic; *Tubbia tasmanica* Whitley: widespread in deep waters in the New Zealand region also known from off the east coast of South Africa and Tasmania.

Full descriptions and synonymies for each species and keys for the identification of New Zealand centrolophids are presented. Knowledge of distribution and habits is reviewed. Where available and of significance, both adults and juveniles are illustrated.

INTRODUCTION

The family Centrolophidae is of only moderate size, containing about seven genera and 30 species. As construed by Haedrich (1967) in his broad review of stromateoid fishes the family contains a strange diversity of fishes whose inter-relationships are poorly understood. In part, this is because some species, particularly several of the more unusual ones, are known only from few adults, others only from juveniles. Thus the suggestion of Ahlstrom *et al.* (1976), that the centrolophid genus *Ichthyos* Jordan and Gilbert may warrant full familial recognition, may eventually be found to be true also of other centrolophid genera or generic groups. In the meantime genera assigned to the family by Haedrich (1967) are retained within the family. These genera include:

- (1) *Hyperoglyphe* Günther: very stout, blunt-headed and thick-bodied;
- (2) *Centrolophus* Lacépède: similar but more elongated;
- (3) *Seriola* Guichenot: varies from *Hyperoglyphe*-like to more elongate and streamlined;
- (4) *Psenopsis* Gill: small, relatively shallow-bodied but thick;
- (5) *Ichthyos* Jordan and Gilbert: shallow-bodied, thin and rather limp;
- (6) *Schedophilus* Cocco (*sensu* Haedrich, 1967): appears to be something of a "catchall" genus, including some *Ichthyos*-like forms as well as others that seem more akin to *Seriola*;
- (7) *Tubbia* Whitley: resembles *Schedophilus*.

This account of the New Zealand centrolophid fauna follows a series of papers in which I have sought to clarify a number of complex taxonomic problems in various

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centrolophids (McDowall, 1976, 1979, 1980 a, b). It attempts a synthesis of the species, presents generic and specific keys and descriptions, and generally seeks to bring together taxonomic data on New Zealand representatives of a complex and difficult group of fishes.

MATERIALS AND METHODS

Measurements and counts: Methods of measurement used were largely those described by Hubbs and Lagler (1958). Measurements were made with needlepoint dividers and determined to the nearest 0.5 mm. Measurements were taken point to point, as follows: length to caudal fork (L.C.F.); standard length (S.L.); greatest body depth (B.D.); body width — thickness of trunk (B.W.); body depth at vent (B.D.V.) — used in addition to greatest body depth because the latter is affected by sexual maturity; depth of caudal peduncle (D.C.P.); length of caudal peduncle (L.C.P.) — measured from rear of anal fin base; predorsal length (PreD.); preanal length (PreA); length of bases of dorsal and anal fins (L.D.B. & L.A.B.); pectoral fin length (Pec.); pelvic fin length (Pel.); prepelvic length (PrePel.); pectoral-anal length (Pec-An.); pelvic-anal length (Pel-An.); head length (H.L.); head width (H.W.); head depth (H.D.) — taken vertically at the isthmus; snout length (Sn.L.); postorbital head length (P.O.H.L.); interorbital width (I.O.W.) — fleshy interorbital; diameter of eye (D.E.) — horizontal diameter of fleshy orbit; length of upper jaw (L.U.J.); length of lower jaw (L.L.J.); width of gape (W.G.).

The following structures were counted; fin spines and rays in dorsal, caudal, anal, pectoral and pelvic fins (in some species, due to fleshy nature of fins and softness of spines, spines and rays were not distinguished and a total count is given); vertebrae; gill rakers.

Material examined came, in part, from the institutions listed below. Much of this was collected by either the Fisheries Research Division vessel R.V. *James Cook*, the Fisheries Management Division vessel F.V. *W. J. Scott*, the Japanese vessels R.V. *Shinkai Maru* and R.V. *Kaiyo Maru* and the German exploratory trawler F.V. *Wesermunde*. Some of this material has not been retained; some is held by Fisheries Research Division, Wellington, and will eventually be deposited in the collections of the National Museum, Wellington; some, in general the rarer and more unusual material, has already been deposited in that collection. Study material was usually from the New Zealand region. However, in a few instances sufficient or suitable material was not available and specimens from elsewhere in the various species' ranges were used for obtaining data. The following abbreviations for material in various collections appear in the text:

| | |
|------|--|
| AIM | Auckland Institute and War Memorial Museum, Auckland, N.Z. |
| AMS | Australian Museum, Sydney, N.S.W., Australia. |
| BMNH | British Museum (Natural History), London, U.K. |
| CMC | Canterbury Museum, Christchurch, N.Z. |
| ZMH | Zoologisches Museum, Universität Hamburg, Hamburg, Germany. |
| ISH | Institut für Seefischerei, Bundesforschungsanstalt für Fischerei, Universität Hamburg, Hamburg, Germany. |
| JLBS | J.L.B. Smith Institute of Ichthyology, Rhodes University, Grahamstown, South Africa. |
| MCZ | Museum of Comparative Zoology, Harvard University, Cambridge, Mass., U.S.A. |
| MNHN | Museum National d'Histoire Naturelle, Paris, France. |
| NMC | National Museum of Natural Sciences, Ottawa, Ontario, Canada. |
| SIO | Scripps Institution of Oceanography, La Jolla, California, U.S.A. |
| TMH | Tasmanian Museum, Hobart, Tasmania, Australia. |
| UBC | Institute of Animal Resource Ecology, University of British Columbia, Vancouver, B.C., Canada. |
| ZIAs | Zoology Institute, U.S.S.R. Academy of Sciences, Leningrad, U.S.S.R. |
| ZMC | Zoological Museum, Copenhagen, Denmark. |

Material examined is listed in Appendix 1.

FAMILY CENTROLOPHIDAE

Diagnosis: Slender to deep-bodied fishes, somewhat to highly compressed. Dorsal fin with up to nine spines, preceding and sub-continuous to continuous with rayed portion, spines variously stout and hard to soft and flexible. Anal fin usually with three spines.

Pelvic fins present, often very small, usually attached to abdomen by a thin membrane medially, fin folding into a shallow groove. Scales small to moderate, cycloid (weakly ctenoid in some *Schedophilus*), usually deciduous (not *Hyperoglyphe* and some *Seriolella*) scales lacking from head in most forms. Head, and sometimes back, with very numerous small pores. Operculum with one or two weak, flat spines. Usually seven branchiostegals. Mouth moderate to large, reaching to or beyond anterior eye margin. Teeth in jaws fine, more or less uniserial; no teeth on vomer, palatines, mesopterygoids or tongue; a row of fine teeth on basibranchials in some species. Vertebrae usually 25 (incl. hypural), but count higher in some (26 in one *Seriolella*, 30 in some *Schedophilus*, 43-45 in *Tubbia*, 48-60 in *Ichthyos*). Caudal skeleton with six hypurals and three epurals (two in *Ichthyos*).

Moderate to large fishes, seven genera with about 30 species, more or less world-wide, sub-polar to tropical. Mostly pelagic and oceanic, both in surface waters and at considerable depths, but also found over the continental shelf, and some (particularly *Seriolella* and *Psenopsis*) may occur in shallow, inshore waters; some *Seriolella* species enter harbours and bays. (Modified from Haedrich, 1967).

Of the seven genera listed by Haedrich (1967) all but *Psenopsis* occur in New Zealand waters.

KEY TO NEW ZEALAND CENTROLOPHID GENERA

- | | |
|--|----------------------------|
| 1. Dorsal fin origin above pectoral fin bases | 2 |
| — Dorsal fin origin distinctly behind pectoral fin bases | 5 |
| 2. Hard spines at front of dorsal fin, spinous portion almost separate or subcontinuous with rest of fin, clearly distinct if sub-continuous; thick and heavy-bodied | 3 |
| — No distinct spinous portion at front of dorsal fin, spines tending to be soft, grading into branched rays; thin-bodied and limp | 4 |
| 3. Dorsal fin rays up to 20; anal rays up to 16 | <i>Hyperoglyphe</i> p. 105 |
| — Dorsal fin rays 25 or more; anal rays 19 or more | <i>Seriolella</i> p. 110 |
| 4. Vertebrae 43-45 | <i>Tubbia</i> p. 133 |
| — Vertebrae 25-30 | <i>Schedophilus</i> p. 123 |
| 5. Thick and heavy-bodied; vertebrae 25 | <i>Centrolophus</i> p. 120 |
| — Thin-bodied and limp; vertebrae 48-51 | <i>Ichthyos</i> p. 130 |

Hyperoglyphe Günther

Hyperoglyphe Günther, 1859: 337 (type species: *Diagramma porosa* Richardson, 1848: 26, by original monotypy, syn. *Perca antarctica* Carmichael, 1818: 501).

Eurymetopos Morton, 1888: 77 (type species: *Eurymetopos johnstoni* Morton, 1888: 77, by original monotypy, syn. *Perca antarctica* Carmichael, 1818: 501).

Haedrich (1967) listed further generic synonyms, not applied to the species that occurs in New Zealand, as follows: *Palinurus* DeKay, 1842 (preoccupied by *Palinurus* Fabricius, 1798, Crustacea); *Palinurichthys* Bleeker, 1859, *Palinurichthys* Gill, 1860, and *Pammelas* Günther, 1860 (all replacement names for *Palinurus*); *Ocyerius* Jordan and Hubbs, 1925; and *Toledo* Miranda-Ribeiro, 1951.

The recognition in 1859-60 that the name *Palinurus* was preoccupied prompted three successive replacement names, but the first of these, *Palinurichthys* Bleeker, 1859, post-dated *Hyperoglyphe* Günther, 1859, by five months (Haedrich, 1967).

In addition to the above generic synonyms, Griffin (1928) described the New Zealand species of *Hyperoglyphe* in *Seriolella*, and Regan (1902) placed Richardson's *Diagramma porosa* in *Lirus*. *Lirus* Aggasiz, 1846, is an emendation of *Leirus* Low, 1833, considered to be a synonym of *Schedophilus* Cocco, 1839, *Leirus* Low, 1833 (Pisces) being preoccupied by *Leirus* Dahl, 1823 (Coleoptera) (Haedrich, 1967).

Generic diagnosis: Thick-bodied centrolophid fishes in which the first dorsal fin is low with short, stout spines, the spines abruptly shorter than the rays in the second dorsal fin; first and second dorsal fins scarcely, if separated; first dorsal origin above or very little behind pectoral fin base. Pelvic fin insertion below or a little behind pectoral fin base.

Lateral line arches anteriorly but curving downwards away from dorsal trunk profile and passes along mid-lateral trunk from above middle of anal fin onto caudal peduncle. Vomer, palate and tongue toothless, but sometimes a row of basibranchial teeth present. Scales of moderate size. Haedrich (1967) listed six species.

Only one species, *H. antarctica* (Carmichael), is known from New Zealand waters.

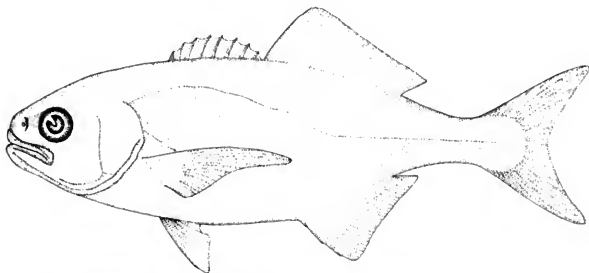


Fig. 1—*Hyperoglyphe antarctica* (Carmichael), 504 mm L.C.F. (FRD-)

***Hyperoglyphe antarctica* (Carmichael) (Fig. 1)**

Perca antarctica Carmichael, 1818: 501 (holotype: none deposited (eaten by ship's crew)); type locality: Tristan da Cunha).

Diagramma porosa Richardson, 1848: 26 (holotype: BMNH 1855.9.19:2, radiograph seen; type locality: coasts of Australia).

Hyperoglyphe porosa: Günther, 1859: 337; Philipp, 1927a: 12; Graham, 1938: 409; 1939: 365; Whitley and Philipps, 1939: 232; Graham, 1953: 22; Whitley, 1956: 405; Graham, 1956: 222; Kaberry, 1957: 91; Graham, 1963: 166; Hewitt, 1963: 61.

Eurumetopus johnstoni Morton, 1888: 77 (holotype: unknown; type locality: Tasmania); Waite, 1912a: 318; 1912b: 200; Philipps, 1921: 120; Thomson and Anderton, 1921: 72; Whitley and Philipps, 1939: 232.

Lirus porosus: Regan, 1902: 202; Hutton, 1904a: 44.

Hyperoglyphe johnstoni: McCulloch, 1914: 78.

Seriotelella amplus Griffin, 1928: 376 (holotype: AIM AF257, not seen; paratype (1): AIM AF258, not seen; type locality: near Mayor Island, Bay of Plenty, New Zealand); Powell, 1941: 259; Parrott, 1957: 60; Doogue and Moreland, 1961: 223.

Seriotelella ampla: Whitley, 1956: 405.

Hyperoglyphe antarctica: Haedrich, 1967: 58; Whitley, 1968: 51; Paul and Robertson, 1979: 123; Paul, 1980a: 5.

Although this species was described under four different specific names, there has never been any question of more than one species of *Hyperoglyphe* occurring in New Zealand waters. Problems have related primarily to the correct name for it.

Common name: A variety of common names has been applied to *H. antarctica* in New Zealand, including "bream", "Griffin's silverfish", and "bluejaw"; current usage seems to favour "bluenose".

Distinguishing characters: *H. antarctica* can be distinguished by a combination of the following characters: two dorsal fins, the first low with eight stout spines, scarcely separate from second dorsal which is much higher; nape scaleless but a small, discrete, ovate patch of scales on each side above and behind eye; mouth large, extending back to about middle of eye; teeth present on basibranchials; lateral line arches upwards from

above opercular opening, follows trunk profile to about vent, then turns down to about mid-lateral trunk and thence straight to tail base; snout truncate.

Description: A stout, heavily-built fish, trunk deep, back and belly evenly arched, greatest depth at about pelvic fin bases; thick-bodied, thickest at about pectoral fin bases, becoming somewhat compressed towards tail. Caudal peduncle short and quite thick, tapering slightly to caudal base, lacking keels. Head large, deep and thick. Eyes of moderate size, set well down on lateral head, somewhat above mid-head depth; an obvious longitudinal concavity above eyes so that median-dorsal head has a rounded crest, and interorbital is sigmoid-shaped in cross-section. Snout very blunt, almost truncate. Jaws about equal, mouth large, cleft slightly oblique reaching to below about middle of eye; lips firm. Anterior nostril a simple opening, posterior one a slit, nostrils close together somewhat nearer tip of snout than eye. Edge of preoperculum thin and bony, finely serrate, opercular margin entire without any obvious spines, or with a flat, weakly developed spine.

Teeth present on premaxilla and dentary, very small uniserial, and close-set; no teeth on vomer, palatine, pterygoids or basihyal, but a median row of tiny teeth along an elevated ridge on basibranchials. Gill openings extensive, opercular membranes not joined to isthmus. Gill rakers moderately long, stout, toothed on inner margins; pyloric caeca numerous, dendritic.

Unpaired fins rather low; first dorsal very low, supported by short and very stout spines, fourth to sixth longest, the fin folding into a groove, fin membrane relatively delicate. Second dorsal scarcely separate from and more than twice as high as first, highest at front and tapering somewhat, outer margin about straight, fin base invested in thick fleshy skin and scaled; fin membrane fleshy and tough.

Caudal fin forked, fin tips pointed. Anal fin of similar shape to second dorsal, origin somewhat behind second dorsal origin. Pectoral fin inserted low, at about 2/3 body depth, fin base moderately oblique, fin long, reaching to about level of vent, upper rays longest, falcate. Pelvic fin a little behind pectoral fin base, small but strongly developed, triangular, folding into a shallow groove, connected to belly by a membrane along inner margin.

Scales of moderate size, cycloid, round to rhomboidal, thin and easily dislodged, covering trunk forward to nape and isthmus, bases of pectoral, second dorsal and anal fins, and about 2/3 caudal fin base. Scales on operculum and preoperculum, but otherwise head naked except for a pair of discrete ovate patches of scales on nape above and behind eyes; about 80-90 scales along lateral line. Head covered with a profusion of very small pores. Lateral line arches upwards from upper opercular opening, follows dorsal trunk profile below first dorsal fin, curves downwards to mid-lateral trunk above and anal fin, and thence runs along mid-lateral trunk to tail base.

Variation: Morphometric: see Table 1.

Meristic: Dorsal — IX (20); 15 (1), 16 (0), 17 (1), 18 (1), 19 (5), 20 (12); anal — III (20); 14 (5), 15 (14), 16 (1); pectoral — 19 (10), 20 (9), 21 (1); gill rakers — 6-1-15 (1), 6-1-16 (2), 7-1-15 (5), 7-1-16 (9), 7-1-17 (2), 8-1-16 (1); vertebrae — 25 (16).

Colour: When fresh a dull bluish-grey on the back, paling to a metallic grey on belly; fins dark metallic grey. In preservative a general dull greyish-brown, back darker, belly paler, no distinct markings.

Size: A large species, known to reach at least 1370 mm L.C.F. and a weight of 36 kg (Graham, 1953). It commonly exceeds 500 mm; small specimens are rarely caught.

Growth: Allometric growth is a widespread phenomenon in centrolophid fishes. However, very few small *Hyperoglyphe* are known. Richardson's (1848) figure of a specimen 140 mm shows form little different from that of large examples, except that the spines at the front of the dorsal fin are relatively longer and the pectoral fin is rounded, rather than falcate.

Distribution: *H. antarctica* is widespread in the Southern Hemisphere, occurring in South Africa, Tristan da Cunha, southern Australia, Tasmania and New Zealand. In New Zealand it probably occurs widely and is recorded from Bay of Plenty, the Chatham Rise between New Zealand and the Chatham Islands, and Otago coasts, from moderately deep waters.

Little is known of the biology of *H. antarctica*, but it seems to be a moderately deep-water, benthic species, taken on long-lines or bottom trawls, down to at least 475 m. Graham (1953) reported that it became common in Otago catches when fishermen began to use long-lines in deep waters over reefs, being caught "only from rocky

Table 1 — Morphometric variation in *Hyperglyphe antarctica*, *Seriotelella punctata*, *S. caerulea*, *S. brama*, *S. labyrinthica* and *Centrolophus niger*. (Figures given as percentages of denominators in ratios).

| | <i>H. antarctica</i> | | | <i>S. punctata</i> | | | <i>S. caerulea</i> | | |
|--------------------|----------------------|-------|------|--------------------|-------|------|--------------------|-------|-------|
| | Range | Mean | S.D. | Range | Mean | S.D. | Range | Mean | S.D. |
| BD/SL | 32.7-38.8 | 34.50 | 1.54 | 26.9-33.1 | 30.11 | 1.35 | 34.5-48.8 | 40.45 | 4.35 |
| BDV/SL | 28.1-33.8 | 30.64 | 1.48 | 9.8-17.3 | 14.02 | 1.55 | 13.1-17.3 | 15.19 | 1.19 |
| BW/SL | | | | 23.6-29.3 | 26.02 | 1.43 | 31.6-44.0 | 35.97 | 3.91 |
| LCP/SL | 15.4-20.3 | 18.64 | 1.29 | 11.0-13.8 | 12.43 | 0.61 | 11.8-17.6 | 14.47 | 1.53 |
| DCP/LCP | 44.6-59.8 | 48.82 | 4.11 | 42.9-70.0 | 55.09 | 6.05 | 42.7-76.9 | 57.01 | 8.63 |
| Pre D/SL | 34.8-42.3 | 38.08 | 1.53 | 31.7-36.6 | 34.44 | 1.18 | 34.8-38.9 | 36.48 | 1.08 |
| Pre A/SL | 64.5-70.3 | 66.58 | 1.51 | 61.4-69.0 | 65.14 | 1.83 | 62.1-68.4 | 65.75 | 1.87 |
| Pre D/Pre A | 53.6-61.9 | 57.18 | 2.24 | 49.5-56.6 | 52.95 | 2.25 | 50.9-61.1 | 55.53 | 2.66 |
| LDB/SL | 26.3-32.4 | 30.33 | 1.27 | 56.3-61.8 | 58.78 | 1.23 | 53.5-60.6 | 57.11 | 1.59 |
| LAB/SL | 19.2-22.9 | 21.18 | 0.98 | 23.6-28.6 | 26.60 | 1.45 | 25.2-32.2 | 28.53 | 2.10 |
| Pec/Pec-An | 72.0-94.3 | 81.61 | 5.79 | 55.6-76.8 | 65.04 | 5.77 | 64.1-84.7 | 72.47 | 6.40 |
| Pel/Pel-An | 44.0-55.4 | 50.74 | 3.42 | 29.8-45.1 | 37.48 | 4.40 | 34.4-72.5 | 46.41 | 12.85 |
| Pre Pel/SL | 34.5-39.2 | 36.73 | 1.07 | 34.9-37.6 | 36.37 | 0.80 | 36.2-41.4 | 37.74 | 1.58 |
| Pec-An/SL | 35.2-42.4 | 38.77 | 1.76 | 33.5-42.1 | 37.87 | 2.39 | 35.5-41.7 | 39.22 | 1.96 |
| Pel-An/SL | 30.8-36.3 | 34.59 | 2.55 | 28.0-35.6 | 31.01 | 2.22 | 25.1-36.0 | 31.18 | 3.19 |
| HL/SL | 31.9-36.2 | 33.40 | 0.97 | 26.3-30.6 | 28.97 | 1.48 | 28.3-32.5 | 30.59 | 1.38 |
| HW/HL | 50.0-61.8 | 57.31 | 3.96 | 38.5-57.3 | 48.76 | 5.83 | 44.2-57.6 | 51.21 | 3.96 |
| HD/HL | 78.7-93.4 | 85.63 | 4.17 | 74.7-92.4 | 82.37 | 4.85 | 77.8-98.1 | 87.19 | 5.63 |
| SnL/HL | 26.7-32.4 | 29.60 | 1.54 | 26.1-34.6 | 30.55 | 1.96 | 23.0-29.7 | 26.89 | 1.82 |
| POHL/HL | 49.4-54.7 | 52.88 | 1.53 | 44.1-55.3 | 51.53 | 2.42 | 49.0-54.1 | 51.64 | 1.54 |
| IOW/HL | 36.7-43.8 | 39.71 | 1.95 | 26.0-37.5 | 32.04 | 2.99 | 31.3-39.6 | 35.29 | 2.23 |
| DE/HL | 20.2-24.1 | 21.89 | 0.86 | 14.7-22.7 | 19.06 | 1.98 | 23.0-27.2 | 25.06 | 1.32 |
| LUJ/HL | 42.7-49.4 | 44.94 | 1.45 | 29.4-35.1 | 33.36 | 1.39 | 31.3-37.0 | 34.33 | 1.56 |
| LLJ/HL | 40.7-47.0 | 43.56 | 1.71 | 30.0-34.6 | 32.13 | 1.29 | 30.7-33.8 | 32.61 | 1.00 |
| WG/HL | 33.6-49.4 | 42.14 | 4.05 | 18.2-31.3 | 24.38 | 3.84 | 28.7-38.8 | 33.41 | 4.18 |
| number measured | 20 | | | 23 | | | 16 | | |
| length range (LCF) | 474-782 mm | | | 102.5-582 mm | | | 192-632 mm | | |

| | <i>S. brama</i> | | | <i>S. labyrinthica</i> | | | <i>C. niger</i> | | |
|--------------------|-----------------|------------|------|------------------------|--|--|-----------------|-------------|------|
| | Range | Mean | S.D. | | | | Range | Mean | S.D. |
| BD/SL | 32.8-37.3 | 35.77 | 1.18 | 42.9 | | | 24.7-29.6 | 27.0 | 1.48 |
| BDV/SL | 16.3-20.6 | 18.52 | 1.06 | 18.9 | | | 11.1-13.7 | 12.23 | 0.75 |
| BW/SL | 29.4-32.8 | 30.77 | 0.90 | 41.1 | | | 22.4-27.2 | 25.00 | 1.43 |
| LCP/SL | 13.3-17.2 | 15.76 | 0.88 | 18.8 | | | 17.7-19.6 | 18.55 | 0.69 |
| DCP/LCP | 37.4-46.5 | 40.92 | 2.40 | 62.6 | | | 32.8-41.7 | 37.39 | 3.15 |
| Pre D/SL | 32.0-35.0 | 33.26 | 0.77 | 26.5 | | | 28.8-36.8 | 33.40 | 2.80 |
| Pre A/SL | 59.3-64.6 | 62.96 | 1.39 | 57.8 | | | 54.9-58.4 | 56.34 | 1.24 |
| Pre D/Pre A | 50.7-55.8 | 53.65 | 1.92 | 45.8 | | | 51.8-65.7 | 59.32 | 4.59 |
| LDB/SL | 50.4-57.7 | 55.30 | 1.72 | 66.6 | | | 46.9-56.5 | 50.65 | 2.95 |
| LAB/SL | 24.2-29.3 | 26.42 | 1.32 | 33.8 | | | 26.4-29.4 | 28.44 | 1.04 |
| Pec/Pec-An | 70.9-90.9 | 80.97 | 5.73 | 71.0 | | | 29.0-42.0 | 37.52 | 3.53 |
| Pel/Pel-An | 31.9-45.2 | 37.44 | 3.82 | 55.3 | | | 16.6-24.5 | 19.64 | 2.99 |
| Pre Pel/SL | 32.7-36.7 | 34.57 | 1.08 | 33.3 | | | 24.2-29.3 | 27.11 | 1.61 |
| Pec-An/SL | 36.9-43.4 | 40.00 | 1.62 | 32.1 | | | 32.1-37.9 | 34.93 | 1.74 |
| Pel-An/SL | 28.0-33.9 | 31.58 | 1.32 | 29.0 | | | 29.2-34.8 | 31.84 | 1.82 |
| HL/SL | 25.6-28.2 | 26.80 | 0.70 | 30.3 | | | 20.7-24.5 | 22.95 | 1.16 |
| HW/HL | 56.8-66.8 | 60.74 | 3.27 | 59.3 | | | 47.0-53.2 | 49.66 | 2.61 |
| HD/HL | 75.6-94.3 | 82.07 | 4.84 | 110.2 | | | 64.6-77.3 | 71.94 | 4.57 |
| SnL/HL | 29.0-37.1 | 31.70 | 2.02 | 28.8 | | | 29.6-34.7 | 31.94 | 1.55 |
| POH/HL | 52.1-56.6 | 54.61 | 1.15 | 54.2 | | | 48.1-54.1 | 50.67 | 2.12 |
| IOW/HL | 36.6-43.3 | 40.14 | 2.03 | 40.5 | | | 31.0-37.7 | 35.19 | 2.10 |
| DE/HL | 15.9-19.7 | 17.71 | 0.91 | 19.1 | | | 16.8-21.1 | 19.90 | 1.46 |
| LUJ/HL | 28.9-33.0 | 30.47 | 0.91 | 33.9 | | | 32.8-37.9 | 34.99 | 1.40 |
| LLJ/HL | 27.6-32.1 | 29.89 | 1.09 | 30.7 | | | 29.0-34.4 | 31.29 | 1.85 |
| WG/HL | 28.3-34.0 | 31.05 | 1.78 | 30.1 | | | 29.0-34.0 | 30.29 | 2.04 |
| number measured | | 20 | | 1 | | | | 10 | |
| length range (LCF) | | 479-619 mm | | 461 mm | | | | 722-1198 mm | |

bottoms". Winstanly (1978) examined the food of this species off southeastern Australia and concluded that it lives in schools near the bottom, feeding above the bottom during the day and moving down onto the bottom, and ceasing feeding, at night. He reported that the food consists primarily of the pelagic tunicate *Pyrosoma*, with some squid, crustaceans and fishes.

Seriolella Guichenot

Seriolella Guichenot, 1848: 238 (type species: *Seriolella porosa* Guichenot, 1848: 239, by subsequent designation, Jordan, 1923: 238, syn. *S. punctata* Forster, in Bloch and Schneider, 1801).

Neptomenus Günther, 1860: 389 (type species *Neptomenus brama* Günther, 1860: 390, by original designation).

Neptomenus (Macleay, 1881) appears to be a mis-spelling of *Neptomenus* which was used by many subsequent workers.

Generic diagnosis: Thick-bodied centrolipid fishes in which the first dorsal fin is low with short, stout spines, the spines abruptly shorter than the single spine and the rays in the second dorsal fin; first and second dorsals scarcely if separated, first dorsal origin above or very little behind pectoral fin base. Pelvic fin insertion below or a little behind pectoral fin bases. Lateral line follows profile of back as far as caudal peduncle, sometimes undulating. Vomer, palate and tongue toothless; basibranchials toothed.

KEY TO SPECIES OF *Seriolella*

1. Caudal peduncle with small, although distinct lateral keels; pectoral fin distinctly falcate, and long. *S. brama* p. 112
- Caudal peduncle with no lateral keels; pectoral fin not or only slightly falcate. 2
2. Head with a distinct dark "mask" which projects back towards dorsal fin as a distinct mediodorsal point; rather slender bodied BDV/SL less than 30%; 42 or more dorsal fin elements. *S. punctata* p. 110
- Head either lacking mask, or if present, lacking distinct mediodorsal point; deeper bodied, BDV/SL 33% or more; 41 or fewer dorsal fin elements 3
3. Eye large ED/HL 23% or more; 35 or more dorsal fin elements; 26 vertebrae *S. caerulea* p. 114
- Eye smaller, ED/ML 19%; 33 dorsal fin elements; 25 vertebrae . *S. labyrinthica*, p. 117

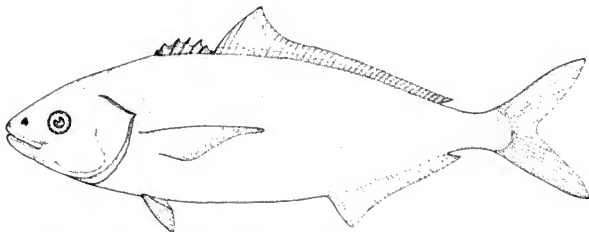


Fig. 2—*Seriolella punctata* (Forster), 536 mm L.C.F. (FRD-)

Seriolella punctata (Forster, in Bloch and Schneider) (Fig. 2)

Scomber punctatus Forster, in Bloch and Schneider, 1801: 37 (syntypes (3): BMNH 1869.2.24:42-44 not seen; type locality: New Zealand — Haedrich, 1967: 40 states "Tasmania", but Bloch and Schneider state "Habitat circa Novam Zeelandiae").

Gasterosteus punctatus Forster, 1844: 140 (syntypes (3): BMNH 1869.2.24:42-44 not seen; the same fish as the syntypes of *Scomber punctatus* Forster, in Bloch and Schneider; type locality: New Zealand. Bloch and Schneider published from Forster's manuscript).

Neptomenus travale Castelnau, 1872: 119 (holotype: unknown; type locality: unstated, fish apparently from "Melbourne Market").

- Neptonemus bilineatus* Hutton, 1873: 261 (holotype: unknown; type locality: Wellington Harbour, New Zealand).
- Seriolaella porosa* Guichenot, 1848: 239 (syntypes (7): MNHNP A6634-6639 not seen; type locality: Valparaiso); Hutton, 1875: 133; 1876: 211; 1890: 278; Gill 1893: 114; Hutton, 1904a: 44; Thomson, 1906: 550; Waite, 1907: 16; Thomson and Anderton, 1921: 73; Phillipps, 1927a: 12; 1927b: 31; Norman, 1937: 115; Graham, 1938: 409; 1956: 22; Whitley, 1956: 405; Haedrich, 1967: 72; Whitley, 1968: 51.
- Neptonemus bilineatus*: Sherrin, 1886: 301 (*Neptonemus* a mis-spelling of *Neptonemus* Günther).
- Seriola porosa*: Sherrin, 1886: 301.
- Seriolaella punctata*: Gill, 1893: 97; Hutton, 1896: 314; Waite, 1911: 231; 1912a: 318; Phillipps, 1921: 120; 1927a: 12; 1927b: 31; Griffin, 1928: 376; Hefford, 1936: 72; Graham, 1938: 408; Parrott, 1957: 58; Haedrich, 1967: 72; Stehman and Lenz, 1973: 179; Robertson, 1975: 6; Francis and Fisher 1979: 5; Paul and Robertson 1979: 123; Paul, 1980b: 6; Grimes and Robertson 1981: 261.
- Seriolaella bilineata*: Hutton, 1890: 278; Gill, 1893: 114; Regan, 1902: 202; Hutton, 1904a: 44; Waite, 1907: 16; Thomson and Anderton, 1921: 73.
- Seriolaella maculata*: Graham, 1953: 221; 1956: 217; Whitley, 1956: 405; 1968: 51; Gavrilov and Markina, 1979: 128 (not *Stromateus maculatus* Forster, 1792, a *nomen dubium*, see McDowall, 1976).
- "Silver warehou": Paul, 1979: 55; 1980a: 5.

Although this species seems always to have been clearly recognised in New Zealand, much confusion derives from its early description by Forster (1844) in the genus *Gasterosteus*. The emergence of another very old Forster name — *Stromateus maculatus* Forster, 1792 — in Graham (1953 — as *Seriolaella maculata* (Forster)) also caused confusion, and has been dealt with elsewhere (McDowall, 1976). The name is a *nomen dubium* and is certainly not a senior synonym of *Seriolaella punctata*.

The inclusion of *S. porosa* Guichenot in the synonymy may be somewhat debatable. I have not examined Chilean material, but Norman (1937) found that *S. porosa* (Chile), *S. dobula* Günther (Tasmania) and *S. punctata* were "very closely related". Haedrich (1967) stated that the counts for *S. punctata* and *S. porosa* are the same. But he argued that "It is unlikely that an essentially coastal fish such as *Seriolaella* would regularly cross the broad expanse of ocean between South America and Australia", and that with study, "*S. porosa*, *S. punctata* and possibly *S. dobula* will probably prove distinct". More recently, Stehman and Lenz (1973) have examined this question in detail and have concluded that the three populations are conspecific.

The name *S. bilineata* (Hutton) is a junior synonym of *S. punctata*, Hutton's species being described under the misapprehension that the fish has two lateral lines, one of these supposed lateral lines being the principal longitudinal sub-dermal mucosal canal, which follows the main longitudinal myoseptum, and which is prominent in *S. punctata*.

Common name: *S. punctata* is commonly and widely known in New Zealand as "silver warehou".

Distinguishing characters: *S. punctata* can be distinguished by its slender form and pointed snout; also by a "mask" of dark coloration on the head extending back to the anterior margin of body scales as a point along the mid-dorsal line. It has a distinct but low anterior spinous dorsal fin with stout spines, and differs from *S. brama* and *S. caerulea*, also from *H. antarctica*, in its high dorsal spine and ray count (*S. punctata* — VII-IX, 35-39; *S. brama* — VII-IX, 25-27; *S. caerulea* — VI-VIII, 30-32; *H. antarctica* — IX, 15-20). It most closely resembles *S. brama*, which has a much longer pectoral fin (pectoral fin 55.6-76.8% of pectoral-anal length, mean 65.04 in *S. punctata*, 81.0-106.0, mean 92.51 in *S. brama*).

Description: Moderately slender, back and belly evenly arched, greatest depth at about mid-abdomen, thick-bodied, becoming compressed towards tail. Caudal peduncle short and quite thick, tapering somewhat to caudal base, lacking keels. Head of moderate size, deep and moderately thick. Eye of moderate size somewhat ovate, vertical axis longest set well down in lateral head, somewhat above mid-lateral, interorbital convex. Snout pointed and rather slender. Jaws about equal, mouth of moderate size, cleft slightly oblique, reaching to below about anterior eye margin, lips firm. Anterior and posterior nostrils ovate slits, close together, much closer to tip of snout than to eye. Edge of preoperculum finely denticulate; opercular margin with weak, flat spine, the spine sometimes lost in large fish also finely denticulate.

Teeth present on premaxilla and dentary, very small, uniserial and close set, becoming biserial laterally in large adults, no teeth on vomer, palatine, pterygoids, or basihyal but teeth on basibranchials. Gill openings extensive, opercular membranes not joined to isthmus. Gill rakers of moderate length, stout, toothed on inner margins; pyloric caeca few (about 3), finger-like.

Unpaired fins low; first dorsal origin above pectoral fin base, fin very low, supported by short, stout spines, second to fourth longest, last spine more or less decumbent without membrane; fin membrane delicate, the fin folding into a groove. Second dorsal scarcely separate from first, more than twice the height of first, highest at front, tapering quickly, outer margin concave, fin base invested in thick fleshy skin, fin membrane tough and fleshy. Caudal fin forked, fin tips pointed. Anal fin similar to second dorsal, origin at about middle of second dorsal. Pectoral fin inserted a little below mid body-depth, fin base moderately oblique, fin of moderate length, reaching only about $\frac{2}{3}$ distance from base to anal origin, upper rays much longer than lower ones, fin somewhat falcate. Pelvic fin origin below pectoral origin, fin small but strongly developed, triangular, folding into a distinct groove, connected to belly by a membrane along inner margin.

Scales small, cycloid, round to rhomboidal, thin and very deciduous, covering trunk forward to nape and isthmus, scale limits on nape very distinct with a flap of tissue covering base of anteriormost scales. Scales present on suboperculum, but operculum, preoperculum and remainder of head scaleless; pectoral, dorsal, and anal fin bases scaled, with scales extending well on to caudal fin base. About 110-120 scales along lateral line. Head and trunk covered with a profusion of small pores connected by a dense reticulum of mucosal canals. Lateral line curves gently upwards from opercular opening, following profile of back to caudal peduncle, somewhat undulating.

Variation: Morphometric: See Table 1.

Meristic: Dorsal — VII (1), VIII (14), IX (1); 35 (2), 36 (4), 37 (8), 38 (0), 39 (2); anal — III (18); 21 (1), 22 (2), 23 (11), 24 (2); pectoral — 19 (1), 20 (8), 21 (6), 22 (2); gill rakers — 5-1-14 (2), 5-1-15 (1), 6-1-13 (2), 6-1-14 (7), 6-1-15 (3), 7-1-13 (1), 7-1-14 (1); vertebrae 25 (20).

Colour: When alive silvery-blue to grey on the back, almost metallic, paling somewhat on the sides and silvery-white on the belly. The head is a dark grey-brown above and around the snout, this coloration extending back around the eyes like a mask to form a distinct mid-dorsal point on the top and back of the head, the mask terminating at the margin of body scales. There is a dark blotch above the pectoral fin base followed, in small specimens, by an irregular lateral series of small dark spots. These tend to be less distinct or lost in larger fish.

Size: The largest specimen examined in this study was 582 mm L.C.F., the species seems quite commonly to exceed 500 mm. Graham (1956) recorded a fish 660 mm weighing about $5\frac{1}{2}$ kg.

Growth: Unlike many centrolophids, *S. punctata* attains approximate adult form at small size; specimens about 100 mm long are easily recognisable as small *S. punctata*, this indicating no obvious changes in shape with growth — nor do measurements from a range of specimens 102.5 to 582 mm L.C.F.

Distribution: Widespread in southern New Zealand waters near the shelf edge and deeper, particularly in the Subtropical Convergence Zone from Chatham Islands to Banks Peninsula and the Snares Islands. Recorded as juveniles from inshore North Island waters as far north as Hauraki Gulf. Not uncommon at Auckland Is. Most common between 300 and 500 m, adults generally range between 200 and 800 m, with juveniles (0+ and 1+) from 50-150 m. Principal recorded spawning/nursery ground at Mernoo Bank. Schools for both feeding (especially on salps) and spawning, but also occurs in small concentrations. Also present in southern Australian and South American waters (Patagonian Chile and Argentina). The eggs of *S. punctata* are discussed by Robertson (1975) and the eggs and larvae by Grimes and Robertson (1981). Gavrilov and Markina (1979) reported that *S. punctata* is a macroplankton eater, living on the tunicate *Pyrosoma*, amphipods, coelenterates and salps.

***Serirolella brama* (Günther) (Figs. 3, 4)**

Neptomenus brama Günther, 1860: 390 (holotype BMNH 1975: 9. 23.1, not seen; type locality: New Zealand); Hutton, 1875: 133; Thomson, 1879: 382; Hector, 1884: 54; Sherrin, 1886: 104; Hutton 1890: 278.

Neptomenus brama: Hector, 1872: 112; Hutton, 1872: 21; 1873: 262; Sherrin 1886: 104; Thomson 1892: 209.

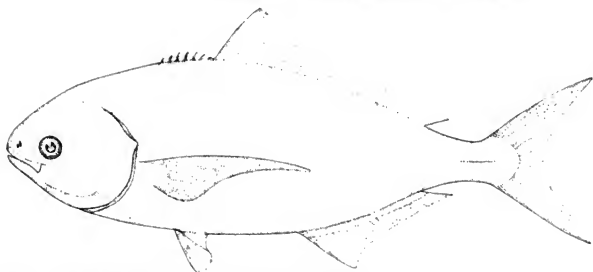


Fig. 3—*Seriolella brama* (Günther), 529 mm L.C.F. (FRD-)

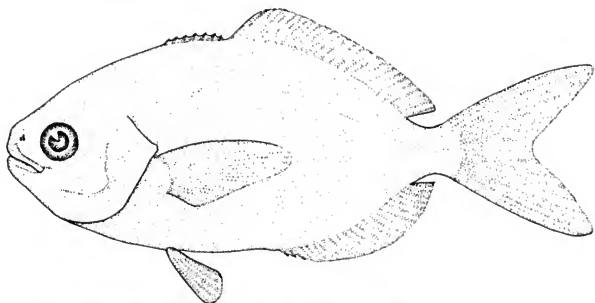


Fig. 4—*Seriolella brama* (Günther), juvenile, 108 mm L.C.F. (FRD-)

Seriolella brama: Hutton, 1890: 278; Gill, 1893: 114; Hutton, 1904a: 44; Thomson, 1906: 550; Waite, 1907: 16; 1911: 229; Thomson, 1913: 230; Phillipps, 1918: 270; 1921: 120; Thomson and Anderton, 1921: 73; Phillipps and Hodgkinson, 1922: 95; Thomson and Thomson, 1923: 111; Buck, 1926: 623; Phillipps, 1927a: 12; 1927b: 31; Griffin 1928: 376; Benham, 1934: 31; 1935: 22; Norman, 1935: 3; Hefford, 1936: 72; Wilson, 1937: 31; Benham, 1938: 56; Graham, 1938: 409; Fowler, 1940: 768; Phillipps, 1947: 50; 1948: 129; 1949: 34; Graham, 1953: 218; Manter, 1954: 543; Graham, 1956: 218; Manter, 1954: 543; Graham, 1956: 218; Whitley, 1956: 405; Parrott, 1957: 63; Doogue and Moreland, 1961: 22; Graham, 1963: 168; Moreland, 1963: 26; McLintock, 1966: 709; Paul, 1966: 552; Haedrich, 1967: 72; Heath and Moreland, 1967: 44; Hewitt, 1968: 1; Tong and Elder, 1968: 65; Whitley, 1968: 5; Robertson, 1975: 14; 1980: 46; Patchell, 1979: 42; Paul and Robertson, 1979: 123; Struik and Bray, 1979: 31; Gavrilov and Markina, 1979: 128; Paul 1980b: 5.

"Common warehou": Paul, 1979: 55; 1980a: 5.

A few taxonomic or nomenclatural problems pertain to *S. brama*, but these are primarily a result of early discussions related to generic allocation. This problem seems stable now, but extensive revision of the centrolophid genera is necessary and could result in change.

Common name: This species is known as "common warehou" or "blue warehou".

Distinguishing characters: *S. brama* is distinguished by its very long and falcate pectoral fins, also the small eyes set deep in the head, small mouth scarcely reaching anterior eye margin, the distinct, low spinous dorsal fin usually with eight spines, and the low but distinct lateral keel on the mid-lateral caudal peduncle.

Description: A large, heavy-bodied species, the trunk deep and thick, moderately compressed, back and belly deeply and evenly arched, greatest depth at mid-abdomen. Caudal peduncle relatively slender and short, tubular. Head large, very deep, much deeper than broad, thick. Eye small, deep set, about mid-depth in head, interorbital deeply convex. Snout tapering to an evenly and bluntly rounded tip. Jaws equal, mouth moderate, cleft only slightly oblique, scarcely or not reaching anterior eye margin, lips firm. Anterior nostril a simple aperture, posterior one an ovate slit, the two separated by a low and very narrow crest, nostrils much closer to tip of snout than eye. Edge of preoperculum free, smooth to softly denticulate; operculum projecting back above pectoral fin base as a soft flat spine. Gill openings extensive, opercular membranes not joined to isthmus. Gill rakers of moderate length, stout, toothed on inner margins. Teeth present on premaxilla and dentary, very small, uniserial, cardiform, no teeth on vomer, palatine, pterygoids, basihyal or basibranchials. Pyloric caeca numerous, branching. Unpaired fins rather low. First dorsal origin a little behind pectoral fin base, low, with short stout spines, 2nd to 4th spines longest but length fairly even, fin membrane delicate; second dorsal abruptly higher than first, anterior rays much the longest, these rapidly shortening and then fin low, margin roughly parallel to back, fin base invested in thick skin. Caudal fin deeply forked, fin tips pointed. Anal fin similar in form to second dorsal, originating below about middle of second dorsal. Pectoral fin inserted at a little below half body depth, level with lower eye margin, fin base moderately angled, fin long, reaching well towards level of vent, upper rays much the longest, fin strongly falcate. Pelvic fin origin distinctly behind pectoral base, strongly developed, outer rays longest, fin connected to belly along inner margin by a weak membrane (often fractured), fin folding into a distinct but shallow groove on belly.

Scales of moderate size, thin and deciduous, about 90 along lateral line covering trunk but top and sides of head largely scaleless except for a patch of scales on operculum. Top and upper sides of head with a profusion of small pores. Lateral line curves upwards from upper opercular opening and then more or less follows profile of back to tail base, somewhat undulatory.

Variation: Morphometric: See Table 1.

Meristic: Dorsal — VII (1), VIII (12), IX (26); 25 (8), 26 (7), 27 (17), 28 (4), 29 (3); anal — III (39); 19 (1), 20 (4), 21 (10), 22 (22), 23 (2); pectoral — 19 (13), 20 (17), 21 (9), 22 (1); gill rakers — 6-1-15 (1), 6-1-16 (7), 6-1-17 (16), 6-1-18 (1), 7-1-15 (1), 7-1-16 (6), 7-1-17 (5), 7-1-18 (2), vertebrae — 25 (11).

Colour: When fresh a steely blue to greenish-grey, slightly paler on belly, operculum and lower jaw somewhat metallic pink, eye blue-black, a large blackish blotch above pectoral fin reaching towards back. In preservative back brownish to grey-black, belly greyish, black blotch above pectoral fin evident.

Size: The largest specimen examined was 603 mm L.C.F. Doogue and Moreland (1961) report it reaching "3 feet" (914 mm) and Scott *et al.* (1975) 30" (= 760 mm); *S. brama* seems commonly to exceed 550 mm in length.

Growth: As in most centrolophids, young *S. brama* are much deeper bodied and are more compressed than adults (Fig. 4). However, changes, in form with growth are not as striking as in some other species.

Distribution: *S. brama* is widespread in southern New Zealand coastal waters; it occurs patchily along west coast of North Island, and is uncommon or rare on the northeast coast. Occurs from subtidal reefs down to 200 m and is most common on the inner shelf. Not reliably reported from New Zealand's southeastern offshore islands and banks. Present in southern Australia. Schools, at least seasonally, probably for feeding as well as spawning. The eggs of *S. brama* were described by Robertson (1975) and spawning by Robertson (1980). Gavrilov and Markina (1979) reported that *S. brama* is a macroplankton eater, living primarily on the tunicate *Pyrosoma*, the salp *Iasis*, and the euphausiid *Nyctiphanes*.

Seriolaella caerulea Guichenot (Figs. 5, 6)

Seriolaella caerulea Guichenot, 1848: 242 (holotype: apparently lost — Norman, 1937: 116; type locality: Juan Fernandez) Paul, 1978: 13; McDowall, 1980a: 6; Paul and Robertson, 1979: 123; Paul, 1980b: 5; McDowall, 1980c: 6.



Fig. 5—*Seriolella caerulea* Guichenot, 605 mm L.C.F. (FRD-)

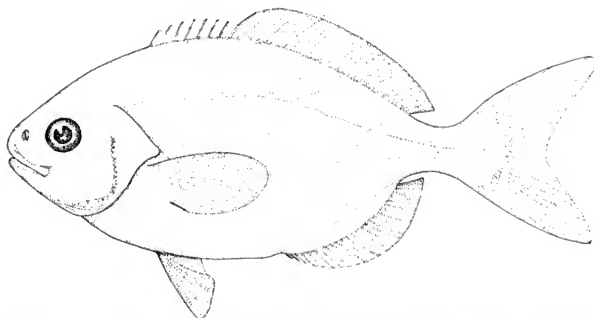


Fig. 6—*Seriolella caerulea* Guichenot, juvenile 196.5 mm L.C.F. ("*griseolineatus*" type) (NMW 3192)

Schedophilus maculatus Waite, 1904: 163; 1910a: 375 (not *S. maculatus* Günther, 1860).

Palinurichthys griseolineatus Norman, 1937: 117 (holotype: BMNH 1936.8.26: 1070 not seen; paratype (1): BMNH 1936.8.26: 1071, not seen; type locality: off the Atlantic Coast of Patagonia, 49° 00'S, 61° 58'W).

Palinurichthys caeruleus Norman, 1937: 116.

Schedophilus griseolineatus Haedrich, 1967: 62.

Seriolella tinro Gavrilov, 1973: 631 (holotype: ZIAS 41-163 not seen; paratypes (30): ZIAS no number, not seen; type locality: Mernoo Bank, east of New Zealand, 43° 28'65'S, 176° 11'E, from 400 m); Eggleston, 1975: 7; Paul and Cawthorn, 1977: 3; Gavrilov and Markina, 1979: 128.

"White warehou" Paul, 1979: 55; 1980a: 5.

Problems related to the taxonomy of *S. caerulea* are discussed in McDowall (1980a). In brief, the conclusion of Norman (1937) was adopted, namely that the Chilean *Seriolella* with 26 vertebrae is the fish Guichenot (1848) described as *S. caerulea*. *S. griseolineatus* Norman was shown to be the juvenile of *S. caerulea*, both forms being present in New Zealand and agreeing with *S. tinro* Gavrilov (McDowall, 1980a). Generic assignment of

this species is problematical in view of the placement by Haedrich (1967) of *S. griseolineatus* in the genus *Schedophilus* Cocco. That placement is rejected here.

Description of this fish under the name *Seriotelella caerulea* predated my notification of a centrolophid specimen from Juan Fernandez in the collection at Scripps Institution of Oceanography, at La Jolla, which was registered there as *Neptomenus crassus* Starks (*N. crassus* is not the same as *Centrolophus crassus* Valenciennes (in Cuvier and Valenciennes, 1833)). This specimen is NOT *Seriotelella caerulea* as it has 25 vertebrae, so that the assignment of the name *caerulea* to the form from Australia, New Zealand and Chile with 26 vertebrae may be argued. This argument seems unlikely to be settled by comparisons of these two similar fish species with Guichenot's (1848) meagre original description.

There is already a species from Juan Fernandez with 25 vertebrae. If intensive collecting of fishes around Juan Fernandez reveals only this one species, the name *caerulea* would then probably apply to it. In the meantime, however, I propose that the name *S. caerulea* Guichenot be retained for the species with 26 vertebrae following the usage of Norman (1937) and thus maintaining stability. Should it be shown that the name is not appropriate then the correct name would be *S. griseolineatus* (Norman, 1937), a species described from the coast of Argentina.

Common name: This species has become known as "white warehou".

Distinguishing characters: *S. caerulea* is distinct from all other centrolophids in having 26 vertebrae (including hypural). Its large eye (23.8-27.3% of H.L.) is also distinctive as is its very deep body (BDV 33.1-44.0% of S.L.). The absence of a dark blotch above and behind the pectoral fin base enables *S. caerulea* to be distinguished easily from *S. punctata* and *S. brama*. Its lateral line tends to be undulatory.

Description: A large, heavy-bodied species, the trunk very deep and thick, moderately compressed, back and belly deeply and evenly arched, greatest depth just behind pelvic fins. Caudal peduncle of moderate depth, short, and somewhat compressed. Head large, very deep, much deeper than broad, somewhat compressed. Eye large, set well down on head, interorbital convex. Snout very blunt, rounded. Jaws equal, mouth large, cleft moderately oblique, reaching to a little beyond anterior eye margin; lips firm. Anterior nostril a simple aperture, posterior nostril an ovate slit, openings very close together, nostrils nearer tip of snout than eye. Edge of preoperculum denticulate, operculum extending back over pectoral fin base as a soft flat spine. Gill openings extensive, opercular membranes not joined to isthmus. Gill rakers of moderate length, stout, toothed on inner margins. Teeth present on premaxilla and dentary, very small, uniserial and cardiform, no teeth on vomer, palatines, pterygoids, basihyal or basibranchials; pyloric caeca numerous, small, branching.

Unpaired fins rather low. First dorsal originates above pectoral fin base, very low, supported by thick, but flexible spines, fourth to sixth spines longest, fin folding into a shallow groove, fin membrane delicate; second dorsal scarcely separate from first, highest at front, tapering rapidly and then fin margin about parallel to trunk, fin base invested in thick skin. Caudal fin forked, fin tips pointed. Anal fin similar in form to second dorsal, originating below about middle of second dorsal. Pectoral fin inserted at about two-thirds body depth, level with lower eye margin, fin base moderately angled, fin reaching about two-thirds or more of distance to vent, upper rays longest, semi-ovate to falcate in shape. Pelvic fin origin a little behind pectoral origin, fin strongly developed, triangular, outer rays longest, fin connected to belly by membrane along inner margin, folding into an indistinct, shallow groove on belly.

Scales, small, cycloid, thin and very deciduous, about 120 along lateral line, covering trunk forward onto nape to about level of eyes, bases of pectoral, second dorsal, anal, and caudal fins. Operculum scaled but head otherwise naked. Head covered with a profusion of very small pores. Lateral line arches from above opercular opening, passes about parallel to upper trunk profile, never becoming straight along mid-lateral trunk, irregular and undulating below second dorsal fin.

Variation: Morphometric: See Table 1.

Meristic: Dorsal — VII (6), VIII (10); 30 (2), 31 (8), 32 (3), 33 (3); anal — II (2), III (14); 19 (1), 20 (0), 21 (4), 22 (5), 23 (5), 24 (1); pectoral — 20 (5), 21 (6), 22 (4), 23 (1); gill rakers — 6-1-12 (1), 6-1-13 (3), 6-1-14 (3), 6-1-15 (2), 6-1-16 (2), 7-1-13 (1), 7-1-15 (2), 7-1-16 (1), 8-1-15 (1); vertebrae — 26 (11).

Colour: When fresh silvery-grey to creamy-white, no distinctive markings. In Preservative dull grey to creamy-white, head somewhat brownish. Juvenile coloration highly distinctive (see "Growth").

Size: Gavrilov (1973) reported on 31 specimens 350-570 mm S.L. (= 385-625 mm L.C.F.). The largest I have seen was 632 mm L.C.F.

Growth: Allometry during growth is prevalent amongst centrolophid fishes and is evident in *S. caerulea* (Table 1 in McDowall, 1980a). The young are rather deeper bodied than the adults. Also, the dorsal and anal fins in the young are higher and more rounded, becoming lower and more falcate in large adults; the rounded pectoral fin of the young becomes increasingly ovate to falcate in shape, with growth.

Coloration varies with growth, the young fish having distinctive longitudinal, irregular, pale and dark grey stripes (Fig. 6) which disappear with growth.

Distribution: *S. caerulea* occurs widely in the southern temperate Pacific encompassing Tasmania, New Zealand, Juan Fernandez and Pacific and Atlantic coasts of Patagonian South America. In New Zealand it is found in southern offshore waters, largely south of the sub-tropical convergence, and is particularly abundant and widespread in waters to the south and east of the South Island — Banks Peninsula to Chatham's, Snares, Auckland and Campbell Islands. It is taken in this area — on the Mernoo Bank, Bounty Rise and Campbell Plateau — in large numbers by deep-sea commercial fishing trawlers using bottom trawls, mostly at depths between 400 and 600 m, less often up to about 200 m and down as far as 700 m. It is also present on the west coast of the South Island. It seems to occur in schools, with sporadic large catches being made. P. Last (pers. comm.) reports this species "common in depths greater than 300 fathoms off the west coast of Tasmania". Depth of capture of large numbers is inversely related to latitude. These are all catches of adults and very little is known about the distribution of juveniles. Like other stromateoids, the young of *S. caerulea* may be surface living. Gavrilov and Markina (1979) found that *S. caerulea* feeds primarily on the salp *Iasis* and to some extent on the tunicate *Pyrosoma*.

Dr D. A. Robertson (pers. comm.) has obtained ripe eggs of *S. caerulea* and fertilised them (see McDowall, 1980a).

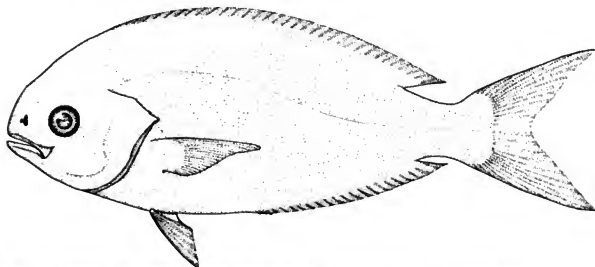


Fig. 7—*Seriolella labyrinthica* (McAllister and Randall), 461 mm L.C.F. (NMW 8020)

***Seriolella labyrinthica* (McAllister and Randall) (Fig. 7)**

Schedophilus labyrinthicus McAllister and Randall, 1975: 1 (holotype: MNC 67-501, radiograph seen; paratypes: (1) UBC 65-411 not seen; (1) BPBM 6642, not seen; type locality: near Easter Island).

Schedophilus oculis Stehman and Lenz, 1973: 190 (partim?)

Taxonomy: Generic allocation of this species is problematical. McAllister and Randall (1975) assigned it to *Schedophilus*, following Stehman and Lenz's (1973) view that the "*Schedophilus ovalis* species group" has "two free predorsal interneurals, as opposed to three in the others of the genus and in the related genera *Seriolella* and *Hyperoglyphe*". However, this would seem to be a character of limited value as an indicator of relationships inasmuch as the "two predorsals" condition can best be regarded as derived by loss, and therefore relatively easily repeated in different groups. *Seriolella labyrinthica* may belong in the same genus as *Schedophilus ovalis*, but I doubt that it belongs with *S. medusophagus* (type species of *Schedophilus*) and *S. huttoni*. Although this fish does not have as distinct a separation of the spinous and branched-rayed dorsal fins as is true, for instance, of *Seriolella punctata*, and as is stipulated by Haedrich (1967) in his diagnosis of *Seriolella* it seems to me that it belongs more properly in *Seriolella* than in *Schedophilus*. Stehman and Lenz (1973) reached the contrary conclusion, but admitted having little familiarity with adults of *Schedophilus*. It is critical to again emphasise that the nature and scope of this problematical genus must relate to the characters of the type species *S. medusophagus* and is not particularly affected by the characteristics of the additional rather diverse species aligned with it by a variety of workers.

Stehman and Lenz (1973) also suggest that three nominal species — *Seriolella velaini* Sauvage 1879, *Seriolella christophersoni* Sivertsen, 1946 and *Schedophilus labyrinthicus* — are junior synonyms of *Schedophilus ovalis* (Valenciennes, in Cuvier and Valenciennes, 1833). However, McAllister and Randall (1975) examined this question in some detail and came to the conclusion that their specimens were distinct, thus describing them as *Schedophilus labyrinthicus*.

Comparison of meristic data in *S. labyrinthica* and *S. violacea* Guichenot (1848) shows that counts are virtually identical — *S. labyrinthica* (from McAllister and Randall, 1975) dorsal VII-VIII + 26-29; anal III + 18-19, pectoral i 20-22; gillrakers 7 + 1 + 16-18; vertebrae 10 + 15. *S. violacea* (from Haedrich, 1967) — dorsal VII-VIII + 25-28; anal III + 18-20; pectoral 21-22; gillrakers 5-7 + 1 + 16-18; vertebrae 11 + 14.

On the basis of these data, there would be little hesitation in declaring the two species synonymous. However, *S. labyrinthica* has the spinous and rayed portions of the dorsal fin continuous, lacking a distinct and separate spinous dorsal, whereas, *S. violacea* is shown by Chirichigno (1974) to have the spinous dorsal fin low and distinctly separable from a much higher rayed dorsal fin. This is a marked difference — one of the chief differences between the genera *Seriolella* and *Schedophilus*, as defined by Haedrich (1967) — and therefore precludes treatment of *S. violacea* and *S. labyrinthica* as synonyms. Furthermore, *S. violacea* is described (Stehman and Lenz, 1973) as having pyloric caeca in a dendritic mass ("baumchenantiger Masse") whereas in *S. labyrinthica* they are few and fingerlike. The meristic similarities between *S. violacea* and *S. labyrinthica* are thus deceptive and do not indicate identity of the two species.

The New Zealand specimen described here is in broad and general agreement with McAllister and Randall's species, and their specific name is therefore used.

Stehman and Lenz (1973) and Ahlstrom *et al.* (1976) have discussed at some length the suggestion that *S. labyrinthica* and *Schedophilus ovalis* may prove to be geographical variants of the one species.

This question and the additional question of whether *S. christophersoni* and *Seriolella labyrinthica* are synonyms of *Schedophilus velaini* must await the acquisition of additional material and perhaps a general revision of the genus *Schedophilus*, possibly also of *Seriolella*. The collection of a specimen off Juan Fernandez (SIO 65-650-42) that resembles *S. labyrinthica*, *S. velaini* and *S. christophersoni* further adds to the confusion and makes broad re-evaluation of this species group imperative when sufficient material becomes available.

Common name: none.

Distinguishing characters: A chunky, stout and firm-bodied species, snout blunt, first (spinous) dorsal fin low, grading into second (soft rayed) dorsal. Differs from *S. punctata* in being much deeper bodied (B.D.V./S.L. 41.1% compared with 23.6 — 29.3% in *S.*

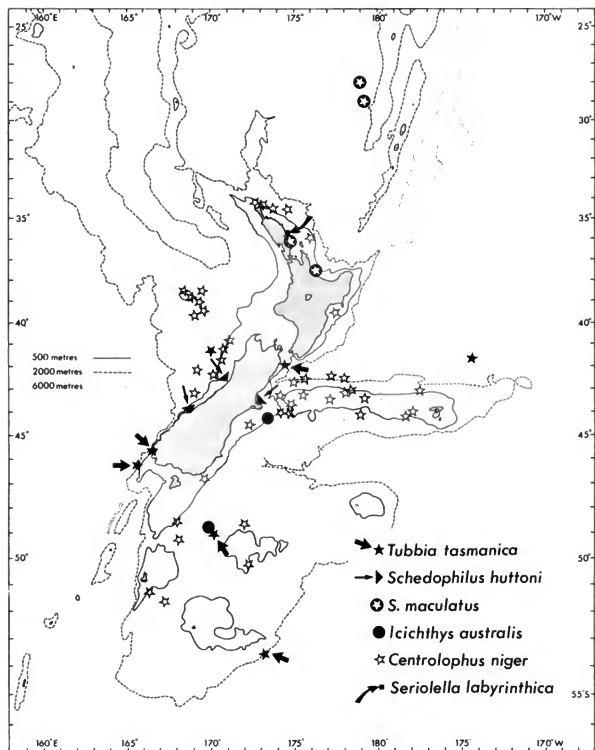


Fig. 8—Distribution in New Zealand waters of the rarer centrolophids — *Tubbia tasmanica*, *Schedophilus huttoni*, *S. maculatus*, *Ichthyos australis*, *Centrolophus niger*, and *Seriolella labyrinthica*.

punctata) having much fewer dorsal fin elements (33, compared with 42–48) and lacking the dark head mask; differs from *S. caerulea* in having fewer elements in the dorsal fin (33, compared with 36–40 in *S. caerulea*), 25 rather than 26 vertebrae, and much smaller eyes (E.D./H.L. 19.1% compared with 23.0 — 27.2%); differs from *S. brama* in usually having smaller and non-falcate pectoral fins (Pec./Pec.An. 71.0% compared with 70.9 — 90.9%) and in lacking a keel on the caudal peduncle.

Description: Stoutly built, deep-bodied, back distinctly higher than belly is deep, greatest body depth well in advance of mid-abdomen, tapering and becoming compressed towards tail. Caudal peduncle short, deep, and distinctly compressed; lacks keels. Head of moderate size, deep and thick, antero-dorsal edge of head-nape pointed, almost crested. Eye small, set well down in lateral

head, interorbital broad and deeply convex. Snout blunt, almost truncate. Jaws about equal, mouth small, cleft slightly oblique, reaching to about anterior eye margin, lips firm. Anterior nostril small, broadly ovate, posterior nostril larger, a semicircular slit much closer to tip of snout than to eyes, nostrils close together. Edge of preoperculum denticulate, opercular margin with a weak flat spine above pectoral fin base.

Teeth present on premaxilla and dentary, very small, uniserial, cardiform; no teeth on vomer, palatine, pterygoids, basihyal or basibranchials. Gill openings extensive, opercular membranes not joined to isthmus. Gill rakers of moderate length, quite slender. Pyloric caeca few and fingerlike.

Unpaired fins low; dorsal origin distinctly in advance of pectoral base, about above upper opercular opening, dorsal fin supported by low, stout spines anteriorly, folding into a distinct groove, height of fin rising gently with no distinct change in fin height at last spine, soft-rayed portion of fin highest at front and quickly tapering, fin base invested in thick, fleshy skin. Caudal fin well-forked, fin tips pointed. Anal fin similar in form to soft rayed dorsal, origin at about middle of soft rayed dorsal. Pectoral fin inserted at about $\frac{2}{3}$ body depth, a little below lower eye margin, fin base moderately oblique, fin of moderate length, semi-ovate, upper rays longest. Pelvic fin origin below pectoral base, strongly developed, triangular folding into a well-defined mid-ventral groove, connected to belly by membrane along inner margin.

Scales of moderate size, about 90 along lateral line, strong and adherent, covering trunk, absent from top of head but present on operculum, suboperculum with two rows around anterior margin of preoperculum. Fleshy bases of dorsal and anal fins scaled, small scales extending well out on to caudal fin base. Little obvious development of mucosal canals on head and trunk. Lateral line more or less follows profile of back.

Variation: Morphometric: See Table 1.

Meristic: Dorsal — VII-26; anal — III-21; pectoral — 20; gill rakers — 6-1-16; vertebrae — 25.

Colour: When alive described by collector as "a brilliant violet colour with white vertical bars". In preservative blotchy grey brown, head with distinct pale blotches on nape, above eyes, around nostrils and around angle of jaw; dorsal and anal fins greyish along fleshy bases but dark brown-black along margins, outer fringes of pectorals and pelvics similarly dark brown-black.

Size: Known in New Zealand only from one adult 461 mm L.C.F. McAllister and Randall (1975) record *S. labyrinthica* up to 525 mm S.L. (= ca 620 mm L.C.F.).

Growth: Nothing is known of the young of this species from New Zealand waters. Ahlstrom *et al.* (1976) published data on a juvenile 34.1 mm S.L. in which the head is distinctly longer and the eye larger. Like most centrolophids, the juvenile has a deeper body, much larger dorsal and anal fins, and much longer pelvics. The trunk is covered with irregular darker blotches and vermiculations.

Distribution: From data in McAllister and Randall (1975) and Ahlstrom *et al.* (1976), *S. labyrinthica* is known from Juan Fernandez, Easter and Rapa-iti Islands, Lord Howe Island, and the "central water mass of the South Pacific" as well as now being known from New Zealand. If study shows this species to be synonymous with one or both of *S. christophersoni* and *S. velaini*, range would extend to Tristan da Cunha and/or St Paul (both islands in the southern Indian Ocean).

The sole New Zealand specimen was taken by spear fishermen in the surf at Tutukaka, northeastern shores of the North Island, New Zealand (Fig. 8).

***Centrolophus* Lacépède**

Centrolophus Lacépède, 1803: 441 (type species: *Perca nigra* Gmelin, 1789: 132, by original monotypy).

Haedrich (1967) lists the following names as additional generic synonyms; none of these has any application to the New Zealand region: *Acentrolophus* Nardo, *Gymnocephalus* Cocco, *Pomilus* Lowe and *Centrolophodes* Gilchrist and von Bonde. Parin (1958) considered *Ichthyos* to belong in *Centrolophus* but later (Parin and Permitin, 1969) treated *Ichthyos* as distinct.

Generic diagnosis: Large, thick and firm-bodied centrolophid fishes in which the dorsal fin is continuous, with short soft, flexible spines grading into longer branched rays, dorsal fin origin well behind the pectoral fin bases. Pelvic fin insertion below pectoral fin bases. Lateral line arches a little above pectoral fins but descends to the mid-lateral and

runs straight from about anal fin origin. Vomer, palate, tongue and basibranchials toothless. Checks lack scales; 25 vertebrae.

The genus *Centrolophus* is regarded as being monotypic with one more or less worldwide species, *C. niger* (Gmelin, 1789).

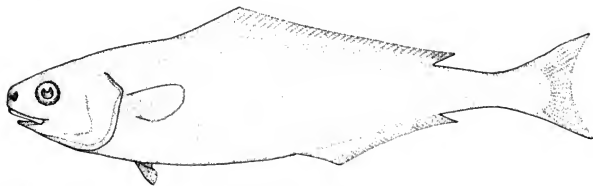


Fig. 9—*Centrolophus niger* (Gmelin), 1035 mm L.C.F. (FRD-).

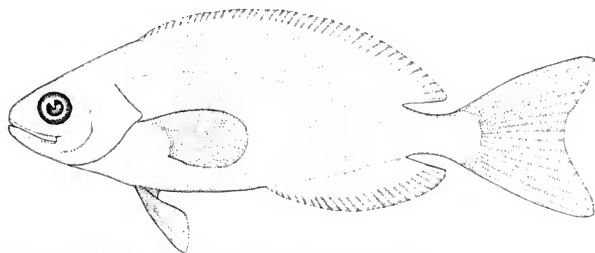


Fig. 10—*Centrolophus niger* (Gmelin), juvenile 108 mm L.C.F. (FRD-)

***Centrolophus niger* (Gmelin) (Figs. 9, 10)**

Perca nigra Gmelin, 1789: 132 (holotype: unknown; type locality "Rivers of Cornwall").

Centrolophus mauricus Ogilby, 1893: 64 (holotype: AMS I.2969, not seen; type locality: New Zealand); Hutton, 1904a: 44; 1904b: 149; Waite, 1907: 16; Regan, 1914: 19; 1916: 144; Thomson, 1926: 19; Phillipps, 1927a: 12; 1927b: 31; Whitley, 1956: 405; 1968: 51.

Centrolophus niger: Regan 1914: 19; Haedrich, 1967: 65; Trunov, 1975: 353; Paul, 1980a: 5.

Schedophilus ovalis: Allen *et al.*, 1976: 435 (not *S. ovalis* Cuvier and Valenciennes 1833: 346).

Taxonomy: Nearly all published New Zealand records of this species are based on early listings and on very few specimens. Haedrich (1967) considered that counts for fish described as *Centrolophus mauricus* from Australia and New Zealand fall "at the high end of the range of *C. niger*", but he nevertheless included New Zealand populations in the cosmopolitan species *C. niger*. This approach is followed here. Dr C. Karrer (pers. comm.) suggested that specimens listed as *Schedophilus ovalis* by Allen *et al.* (1976) are juvenile *C. niger*, a view with which I concur.

Common name: Though scarcely a commonly known fish, when found it is referred to as "rudder fish".

Distinguishing characters: *C. niger* is the largest and amongst the most heavily built of centrolophids in New Zealand waters, although rather more elongate than *Hyperoglyphe*. The very small pelvic fins distinguish *C. niger* from other heavy-bodied species in New Zealand, in this regard resembling the thinner and more flexible-bodied *Schedophilus*, *Tubbia* and *Ichthyos*. Distinguished by thick body, dorsal fin continuous without a distinct spinous dorsal, origin a little behind head, relatively few finger-like pyloric caeca and 25 vertebrae.

Description: Trunk of moderate depth, thick and firm, back and belly not greatly arched, greatest depth at about mid-abdomen. Caudal peduncle quite long, thick. Head of moderate size, thick and of moderate depth. Eyes small to moderate, slightly ovate (long axis vertical), set well down in head, interorbital convex. Snout long, very blunt, truncate. Mouth large, somewhat inferior, lower jaw shorter than upper, tucking inside upper when mouth is closed. Cleft only slightly oblique, reaching a little beyond anterior eye margin. Lips firm. Anterior nostril a simple round aperture, posterior nostril slit-like, openings very close together and very close to tip of snout, almost opening forwards. Edge of preoperculum free with small soft spines, operculum with a weak flat spine above pectoral fin base, edge of bone finely serrate. Teeth present on premaxilla and dentary, very small and close set, uniserial or becoming irregularly biserial laterally in large adults. No teeth on vomer, palatine, pterygoids, basihyal or basibranchials. Gill openings extensive, opercular membrane not joined to isthmus. Gill rakers of moderate length, stout, toothed on inner margins. Pyloric caeca few, finger-like.

Unpaired fins low. Dorsal fin continuous, with short, soft flexible spines grading into longer branched rays, dorsal fin rising as a thick elevated ridge behind head, true origin of fin (first spine) well behind head, fin highest at about 10th to 12th element, subsequent rays lower and fin, on the whole, low and margin slightly concave; fin very thick, almost whole fin invested in thick fleshy skin, fin rays visible only towards fin margin. Caudal fin very weakly forked to emarginate, fin tips pointed. Anal fin similar in form to dorsal, low, very thick and fleshy, fin rays indistinct. Pectoral fin inserted at about mid-body a little above lower margin of eye, fin base quite sharply angled, fin very small not reaching half way to level of vent, upper rays longest, fin semi-ovate to rounded. Pelvic fin origin below pectoral fin base, fin very small not reaching one quarter distance to vent, but thick and fleshy, triangular with outer rays longest, connected to belly by membrane along inner margin, folding into a shallow groove on belly.

Scales cycloid, thin and moderately deciduous, very small, 150 or more along lateral line, covering trunk forward onto nape, to about level of hind margins of eyes, present on pectoral and caudal fin bases and covering most of dorsal and anal fins. Operculum and suboperculum scaled, but head otherwise naked. Head and trunk covered with a profusion of small pores. Sub-dermal mucosal system well developed, skin very thick. Lateral line arches slightly above pectoral fin base, descends to about mid-lateral above vent and then runs along mid-lateral to tail base.

Variation: Morphometric: See Table 1

Meristic: Dorsal (total elements) — 37 (1), 38 (3), 39 (2), 40 (2), 41 (4), 42 (2); anal (total elements) — 24 (2), 25 (6), 26 (4), 27 (1); pectoral — 20 (5), 21 (4), 22 (2); 23 (3); gill rakers — 5-1-13 (1), 5-1-14 (4), 6-1-13 (1), 6-1-14 (6), 6-1-15 (1); vertebrae — 25 (8).

Colour: When fresh, dull coloured, dusky-brown on back paling to silvery-grey on belly, fins all dark grey-brown. Head deep brown, paling on snout in front of eyes to a pale creamish-pink.

In preservative, grey-brown on back, paling to grey-white on belly, head brown with snout a dull creamy-white.

Size: One of the largest stromateoids. Haedrich (1967) mentions one 1200 mm long, while one of those examined in the present study was 1198 mm L.C.F.

Juveniles are less elongate and have higher fins than adults but are less deep-bodied than juvenile *Schedophilus*. They have two distinct broad dark vertical bands on the sides (Fig. 10).

Distribution: *C. niger* has until recently only rarely been reported from New Zealand and in most instances from dead, beach-cast specimens. It has been taken recently in substantial numbers along the West Coast of New Zealand by deep-water trawlers, has been caught on the Chatham Rise east of the South Island, and on the Campbell Plateau to the south. One was caught on a long line in Hawke Bay. Beach-cast specimens have been taken on the Canterbury coast. It is probably widespread in the New Zealand region.

C. niger is known from the North and South Atlantic, Mediterranean, Adriatic, South Africa, Australia and New Zealand. It may well be cosmopolitan in temperate waters.

Large adults taken in trawls have all been caught in relatively deep waters between 400 and 600 m, one sample at 805 m. Sub-adults, 300–350 mm L.C.F. have been taken in purse seines near the surface, and juveniles have been taken also at the surface in a plankton net, around North Cape. Haedrich (1967) reported that the young may be found in surface waters in association with medusae and that the young “are at first vertically banded but by the time they are about 100 mm long they have become a uniform brown”.

Schedophilus Cocco

Schedophilus Cocco, 1839: 57 (type species: *Schedophilus medusophagus* Cocco, 1839: 57, by original monotypy).

Coroplopos Smith, 1966b: 1 (type species: *Coroplopos dicologlossus* Smith, 1966b: 1, by original monotypy).

The genus *Schedophilus* seems ill-defined and inadequately separated from *Seriolella* Guichenot, although the type species of the two genera are very different. Haedrich (1967: 59) diagnosed *Schedophilus* by the “combination of deep body, broad, deep head, large eye, continuous dorsal fin with weak spines graduating to the rays and originating before the pectoral insertion, toothless palate and prominent spines on the preopercular margin”. All of these characters except the “continuous dorsal fin with weak spines graduating to the rays” are in *Seriolella*, and of the species listed by Haedrich under *Schedophilus*, at least one, *S. griseolineatus* (Norman) has the spinous part of the dorsal distinctly and abruptly lower than the soft-rayed portion. (*S. griseolineatus* is in my view (McDowall, 1980a, see also p. 115) the juvenile stage of *Seriolella caerulea* Guichenot.) The problem in diagnosing *Schedophilus* and separating it from *Seriolella* arises partly from the very small numbers of adult *Schedophilus* known, and the marked allometry that occurs during early growth. *Schedophilus* (as typified by *S. medusophagus*) differs from *Seriolella* most obviously in that *Seriolella* (as seen in *S. porosa* Guichenot — the type species, also in *S. brama* and *S. caerulea*) comprises relatively short, thick, and stiff-bodied fishes in which the spinous portion of the dorsal fin is distinctly lower than the soft-rayed portion, the penultimate dorsal spine being sometimes decumbent and followed by a longer spine at the anterior edge of the soft-rayed dorsal fin. By contrast *Schedophilus* contains elongate, thin, and flexible-bodied fishes in which the spinous portion of the dorsal fin can be distinguished from the soft-rayed portion only by dissection of the spines. A recently described species of “*Schedophilus*” — *S. labyrinthicus* McAllister and Randall — is clearly of the thick-bodied, *Seriolella* morphotype, although the dorsal spines are illustrated as graduating into the soft rays (see also p. 118).

I have included *Coroplopos* Smith in the generic synonymy. Even though this form has not been recorded from the New Zealand region, clarification of its identity is possible and seems profitable at this point. *Coroplopos* was diagnosed by Smith (1966b) by the “peculiar nasal opening, apparently single, in a crater-like depression on the side of the snout”. It seemed to me rather surprising that a centrolophid should be described as having but one nostril when all others have two, since the number of nostrils is a particularly stable character in fishes. The explanation appears to be in the condition of the single known specimen. Although Smith (1966b: 2) noted that the “front part of the head is somewhat damaged”, in fact (R. Winterbottom, pers. comm) “The type looks as if it’s been in a head-on collision . . . The whole front of the head has had the skin removed, . . . the jaws are broken, etc. The nasal cavities are there, all right, (ovoids about 1 cm across), but no tissue covers them. Presumably (?) it was either in better condition when Smith saw it, or else he thought the nasal cavity was the anterior nostril”. In view of the fact that in all other respects Smith’s *Coroplopos dicologlossus* resembles *Schedophilus huttoni* (Waite), *Coroplopos* is treated here as a junior synonym of *Schedophilus*. Karrer (1973) reached the same conclusion.

Haedrich (1967) listed eight species of *Schedophilus*; of these, at least one (*S. griseolineatus* (Norman)), is a *Seriolella*, and I suspect that McAllister and Randall’s (1975) *Schedophilus labyrinthicus* is also a *Seriolella*. How many of the remaining species listed by Haedrich (1967) really belong in *Schedophilus* will be determined only when the adults are found. The genus *Schedophilus* (including its close relatives) clearly needs a

broad review. The genus is widespread in the Atlantic Ocean and in the western and eastern Pacific. Two species occur in the New Zealand area.

Diagnosis: Elongate, very compressed, soft-bodied fishes, the dorsal fin originating above the pectoral fin base, anterior dorsal spines soft and flexible, grading into soft rays. Pelvic fin insertion below or a little behind pectoral fin base. Lateral line arches upwards above vent and runs along mid-lateral caudal peduncle. Palate, tongue and basibranchials toothless. Scales very small, deciduous.

KEY TO SPECIES OF *Schedophilus*

- Dorsal fin with more than 50 elements; anal with more than 35; 30 vertebrae *S. huttoni* p. 124
- Dorsal fin with 35-37 elements; anal with 26-27; 29 vertebrae *S. maculatus* p. 125



Fig. 11—*Schedophilus huttoni* (Waite), 685 mm L.C.F. (CMC 113).

Schedophilus huttoni (Waite) (Fig. 11)

Centrolophus mauricus: Hutton 1904a: 44; 1904b: 149; Waite, 1907: 16 (not *Centrolophus mauricus* Ogilby, 1893, a synonym of *C. niger* (Gmelin), 1789).

Centrolophus britannicus: Hutton 1904a: 41; 1904b: 149; Waite, 1907: 16; 1910b: 388; Phillipps, 1927a: 12; 1927b: 31. (not *Centrolophus britannicus* Günther, a synonym of *C. niger* (Gmelin, 1789)).

Centrolophus huttoni Waite, 1910b: 387 (holotype: CMC 113, seen; type locality: beach-cast at Sumner, near Christchurch); Waite, 1912a: 318; Phillipps, 1927a: 12; 1927b: 32; Whitley, 1956: 405; Smith, 1966a: 506; 1966b: 2; Whitley, 1968: 5.

Coroplopus dicologlossus Smith, 1966b: 1 (holotype: JLBS RUSI 604, not seen; type locality: "from deepish water off the Cape of Good Hope? precise depth and locality not known").

Schedophilus huttoni: Haedrich, 1967: 62; Trunov, 1969: 443; Haedrich and Horn, 1972: 40; Karrer, 1973: 239; Trunov, 1975: 351.

Inclusion of *Coroplopus* in *Schedophilus* was discussed following the generic synonymy (p. 123). Inclusion of *C. dicologlossus* in *S. huttoni* follows from this and from the lack of any characters (apart from the supposedly aberrant condition of the nostrils), which distinguish the two species. Trunov (1969) has reported *S. huttoni* from the southeastern Atlantic Ocean, probably not too far from the origin of Smith's specimen. I have included the record of Trunov, from the South Atlantic, in the above synonymy because so very few adult specimens of *S. huttoni* have otherwise been reported. Trunov provided data based on 24 specimens, far more than all previous captures combined.

Common name: *S. huttoni* is a very rarely collected species with no common name.

Distinguishing characters: Elongate, very compressed, and rather limp, dorsal fin originating far forwards over the pectoral fin bases, anterior spines short and soft, ray-like, and grading in length into branched rays, more than 50 elements (spines+rays) in dorsal fin; pelvic fins very small, almost vestigial; 30 vertebrae.

Description: Trunk elongate and very compressed, back and belly only slightly arched, greatest body depth at about mid-abdomen. Caudal peduncle of moderate length, slender and compressed. Head small, compressed, much deeper than broad. Eye of moderate size, deep on lateral head, interorbital convex, snout blunt and somewhat truncate, long. Jaws about equal, mouth large, cleft only slightly oblique, reaching well beyond anterior eye margin; lips firm. Anterior nostril a simple round aperture, posterior one more slit-like, nostrils very close together and much nearer tip of

snout than eye. Edge of preoperculum free, finely denticulate, operculum with one or two flat and very weak spines, posteroventral margin finely denticulate. Teeth on premaxilla and dentary extremely small and fine, uniserial and close-set in a very uniform, comb-like row; no teeth on vomer, palatine, pterygoids, basihyal, or basibranchials. Gill rakers of moderate length, stout, toothed on inner margins; pyloric caeca numerous, long, branching.

Unpaired fins low; dorsal fin continuous, originating just behind head, rising as a low ridge with soft flexible spines grading into soft, branched rays of more or less uniform length, base of fin sheathed in thick skin. Caudal fin somewhat forked, fin tips pointed. Anal fin similar in form to dorsal. Pectoral fin origin somewhat below mid body-depth, base moderately angled, fin small, not reaching $\frac{1}{2}$ distance to vent, upper rays longer, the fin semi-ovate in shape. Pelvic fin origin below pectoral fin base, fin very small, almost vestigial, triangular, attached along medial edge to abdomen. Scales very small, cycloid, somewhat deciduous, 200 or more along lateral line, extending forward onto nape to about level of preoperculum, present on bases of pectoral, dorsal, caudal, and anal fins. Operculum and preoperculum scaled but head otherwise naked. Head covered with a profusion of small pores; these present but not nearly as obvious on trunk. Lateral line arches upwards and then downwards slightly above pectoral fin but then runs more or less straight along trunk to caudal fin base.

Variation: Morphometric and meristic: See Table 2.

Colour: When fresh, unknown.

In preservative a uniform dull greenish-brown to brown, some paler areas on head above operculum and on snout; fins uniformly dark; distinctive markings lacking.

Size: Known from very few specimens up to 800 mm L.C.F. (Karrer, 1973).

Very few small *S. huttoni* are known. Ahlstrom *et al.* (1976) listed five 18.4 to 33.0 mm length. They illustrated a specimen 25 mm long showing it as being quite deep bodied, with very high dorsal and anal fins (up to two-thirds body depth at vent) and dark pigment bars across these fins and extending on to the trunk. Craddock and Mead (1970) collected two (21 and 59 mm) in the southeastern Pacific, off Chile. One of these (MCZ 55142-59 mm) which is badly damaged and appears heavily bleached, shows even larger dorsal and anal fins with darker bars faintly evident in the dorsal fin.

Distribution: Known in New Zealand from beachcast specimens collected at Sumner near Christchurch, near Hokitika, and at Jacksons Bay, South Westland (Fig. 8) and one trawl caught at about 800 m over the Lord Howe Rise to the west of New Zealand; also known from eastern Australia (Australian Museum, Sydney-New South Wales coasts), from the southeastern Atlantic between 18° 47' and 26° 25'S (Trunov, 1969), and the eastern and southeastern Pacific (Ahlstrom *et al.*, 1976; Craddock and Mead, 1970). It is probably southern circumpolar.

Specimens caught by Russian research vessels in the southeastern Atlantic were taken in bottom trawls at depths of between 165 and 570 m. It is enigmatic that *S. huttoni* is known primarily from relatively large specimens; other species of *Schedophilus* are known primarily from juveniles (e.g. see McDowall, 1980b). The juveniles reported by Craddock and Mead (1970) were taken by IKMT between 0 and 200 m, while those of Ahlstrom *et al.* (1976) were captured at the surface by dip net. Haedrich and Neilson (1966) reported a juvenile (40 mm) from the stomach of an *Alepisaurus* taken by longline in the southeastern Pacific.

Trunov (1969) noted that all of the specimens examined in detail, amongst his material, were females, and that a female 720 mm S.L. (L.C.F. 835 mm and weighing 3.55 kg) contained more than 233,000 eggs.

***Schedophilus maculatus* Günther (Figs. 12, 13, 14)**

Schedophilus maculatus Günther, 1860: 412; (holotype: BMNH 1848.3.16: 150, radiograph seen; type locality: China seas); Waite, 1894: 219; Allen *et al.*, 1976: 435; Ahlstrom *et al.*, 1976: 322; McDowall, 1980b: 147; 1981: 492.

Schedophilus marmoratus Kner and Steindachner, 1866: (holotype: listed as ZMH464 by Haedrich, 1967, but Karrer, (pers. comm.) suggests that the holotype is more probably NMV 16724, not seen; type locality: "Sudsee" — Haedrich, 1967: 62, suggested "presumably near Australia").

Hoplocoryphus physalium Whitley, 1933: 68 (holotype: formerly AMS, now lost; paratype (1): AMS IA 5565, seen; type locality: Manly, New South Wales).

| | <i>T. tasmanica</i> | | | | | | | | | | <i>I. australis</i> | | | | | | | | | |
|---------------------------|---------------------|--------|--------|--------|--------|--------|--------|--------|--------|--------|---------------------|--------|--|--|--|--|--|--|--|--|
| BD/SL | 41.2 | 44.1 | 38.3 | 34.6 | 35.9 | 31.9 | 38.1 | 28.3 | 29.0 | 25.6 | 27.1 | 34.1 | | | | | | | | |
| BW/SL | 14.9 | 16.9 | 12.8 | 11.2 | 11.3 | 10.8 | 11.8 | 8.7 | 9.4 | 6.8 | 7.4 | 8.3 | | | | | | | | |
| BDV/SL | 39.5 | 39.0 | 38.3 | 32.3 | 34.6 | 30.7 | 38.1 | 27.5 | 26.9 | 25.3 | 27.1 | 28.1 | | | | | | | | |
| LCD/SL | 12.3 | 11.9 | 10.2 | 13.8 | 12.8 | 13.9 | 12.3 | 13.0 | 11.3 | 13.3 | 12.0 | 10.9 | | | | | | | | |
| DCP/LGP | 107.6 | 82.1 | 92.5 | 74.4 | 67.7 | 58.3 | 78.0 | 69.4 | 76.2 | 64.0 | 69.2 | 80.9 | | | | | | | | |
| Pre C/SL | 38.6 | 42.4 | 28.6 | 30.4 | — | 27.8 | 31.4 | 45.3 | 36.6 | 33.4 | 32.2 | — | | | | | | | | |
| Pre A/SL | 57.9 | 53.4 | 51.7 | 47.2 | — | 49.3 | 50.4 | 63.2 | 56.5 | 55.5 | 56.3 | — | | | | | | | | |
| Pre D/Pre A | 66.6 | 79.4 | 63.3 | 64.4 | — | 56.3 | 62.4 | 71.6 | 64.8 | 60.3 | 57.1 | — | | | | | | | | |
| LDB/SL | 63.2 | 60.2 | 60.2 | 58.4 | 59.1 | 66.8 | 62.2 | 38.4 | 41.9 | 45.5 | 52.4 | 53.4 | | | | | | | | |
| Lab/SL | 38.6 | 34.7 | 39.8 | 40.2 | 43.8 | 44.2 | 40.5 | 21.7 | 24.2 | 28.8 | 25.1 | 28.0 | | | | | | | | |
| Pel/Pec-An | 74.3 | 57.7 | 63.2 | 37.4 | 41.6 | 36.8 | 33.7 | 60.7 | 45.9 | 33.5 | 25.3 | 29.2 | | | | | | | | |
| Pel/Pel-An | 70.0 | 63.6 | 61.7 | 21.0 | 25.6 | 26.7 | 19.8 | 44.3 | 35.3 | 23.6 | 11.6 | 9.5 | | | | | | | | |
| Pre Pel/SL | 36.8 | 19.9 | 28.9 | 26.5 | 25.1 | 24.5 | 22.5 | 28.3 | 30.1 | 23.6 | 25.3 | — | | | | | | | | |
| Pec-An/SL | 26.7 | 33.1 | 25.6 | 27.8 | 27.1 | 27.1 | 29.9 | 30.4 | 32.8 | 38.4 | 38.2 | 42.9 | | | | | | | | |
| Pel-An/SL | 26.3 | 28.0 | 17.7 | 24.0 | 22.5 | 24.3 | 29.9 | 25.4 | 27.4 | 34.7 | 33.8 | 37.4 | | | | | | | | |
| HL/SL | 34.2 | 35.6 | 25.9 | 26.1 | 24.9 | 22.1 | 24.7 | 30.8 | 26.3 | 19.4 | 18.7 | — | | | | | | | | |
| HW/SL | 59.0 | 46.4 | 47.8 | 45.6 | 43.1 | 46.3 | 47.8 | 44.4 | 42.9 | 46.8 | 46.6 | — | | | | | | | | |
| HD/HL | 82.1 | 88.1 | 88.4 | 90.6 | — | 92.7 | 85.1 | 91.7 | 81.6 | 74.6 | 93.3 | — | | | | | | | | |
| SnL/HL | 30.8 | 31.0 | 26.8 | 23.4 | 24.3 | 27.4 | 22.9 | 22.2 | 26.5 | 19.8 | 23.3 | — | | | | | | | | |
| POHL/HL | 50.0 | 47.6 | 55.1 | 57.9 | 57.5 | 53.7 | 59.7 | 52.8 | 49.0 | 65.1 | 65.0 | — | | | | | | | | |
| IOW/HL | 35.9 | 26.2 | 35.5 | 29.2 | 25.7 | 29.3 | 30.4 | 30.6 | 31.6 | 33.3 | 19.0 | — | | | | | | | | |
| ED/HL | 28.3 | 31.0 | 21.7 | 22.2 | 20.7 | 22.0 | 21.9 | 33.3 | 30.6 | 19.8 | 18.4 | — | | | | | | | | |
| LUJ/HL | 51.3 | 50.0 | 42.0 | 38.6 | 35.9 | 43.3 | 38.3 | 40.3 | 36.7 | 28.6 | 28.2 | — | | | | | | | | |
| LLJ/HL | 47.4 | 47.6 | 40.6 | 26.8 | 35.9 | 39.0 | 37.3 | 33.3 | 30.6 | 27.8 | 23.3 | — | | | | | | | | |
| WG/HL | 41.0 | 38.1 | 35.5 | 29.8 | 30.9 | 34.8 | 37.3 | 25.0 | 28.6 | 29.0 | 24.5 | — | | | | | | | | |
| Dorsal fin spines/rays | 51 | 51 | 51 | 47 | 48 | 50 | 47 | 38 | 39 | 39 | 40 | 39 | | | | | | | | |
| Anal fin spines/rays | 34 | 37 | 37 | 34 | 33 | 35 | 34 | 28 | 26 | 29 | 25 | 27 | | | | | | | | |
| Pectoral rays | 21 | 21 | 19 | 19 | 19 | 20 | 18 | 17 | 18 | 17 | 16 | 16 | | | | | | | | |
| Gill rakers | 6-1-14 | 6-1-14 | 6-1-15 | 6-1-13 | 6-1-15 | 7-1-14 | 6-1-12 | 5-1-12 | 5-1-12 | 6-1-10 | 6-1-10 | 6-1-12 | | | | | | | | |
| Vertebrae (incl. hypural) | 44 | 45 | 43 | 43 | 44 | 43 | — | 49 | 50 | 48 | 48 | 49 | | | | | | | | |
| LCF (mm) | 68 | 70.5 | 133 | 373 | 402 | 406 | 450 | 69 | 93 | 324 | 435 | 457 | | | | | | | | |
| | NMW | FRD | NMW | FRD | FRD | NMW | NMW | ISH | ISH | ISH | ISH | FRD- | | | | | | | | |
| | 7612 | — | 7613 | — | — | 7164 | 9761 | 170/76 | 170/76 | 222/76 | 433/71 | ** | | | | | | | | |

** measurements very uncertain owing to poor condition



Fig. 12—*Schedophilus maculatus* Günther, 280 mm L.C.F. (NMW 7638)



Fig. 13—Base of dorsal fin of *Schedophilus maculatus* showing pores opening along fin base.

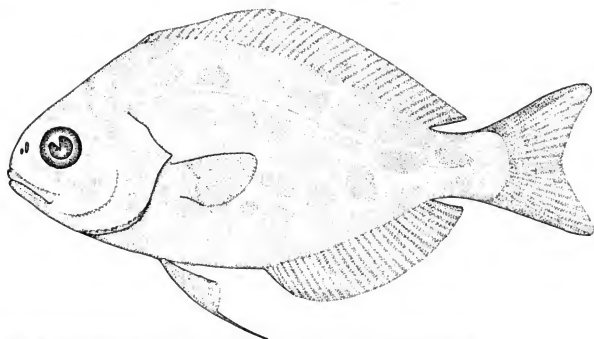


Fig. 14—*Schedophilus maculatus* Günther, juvenile, 99 mm L.C.F. (NMW 4530)

Problems related to the taxonomy of *S. maculatus* were discussed by McDowall (1980b) to which reference should be made for details.

Distinguishing characters: The vertebral count of 29 is diagnostic for this species in the family Centrolophidae. The bold, reticulate blotching covering the head, trunk and fins is characteristic of the much compressed juveniles up to about 100 mm long. Two much larger adults (275, 280 mm L.C.F.) are dark brown, and unmarked. A canal along the base of the dorsal fin, running between the fin-ray bases and opening to the exterior by pores behind each fin ray, appears to be present only in this species (McDowall, 1981).

Description: (based on two adults): Trunk deep and much compressed, back and belly evenly and moderately arched, body shape an elongate oval; greatest body depth at about vent. Caudal peduncle short and deep, strongly compressed. Head of moderate size, very deep, much deeper than broad, much compressed.

Eye large, surrounded by a low rim, set deep in head, interorbital convex. Snout short and very blunt, almost truncate. Jaws about equal, mouth of moderate size, cleft only slightly oblique, reaching back to about middle of eye. Lips thin and firm. Anterior nostril a simple aperture surrounded by a low, fleshy rim, posterior nostril an ovate slit, openings closely adjacent, somewhat nearer tip of snout than eye. Edge of preoperculum free, with numerous, fine spines, operculum with one broad, flat spine above pectoral fin base, and numerous fine spines, like those on preoperculum below. Teeth on premaxilla and dentary, very small, conical, uniserial. No teeth on vomer, palatine, pterygoids, basihyal or basibranchials. Gill openings extensive, opercular membranes not joined to isthmus. Gill rakers of moderate length, stout, toothed on inner edges.

Unpaired fins long and rather low, dorsal fin origin above opercular opening, low anteriorly with short spines, grading into longer branched rays, fin base heavily sheathed by fleshy skin, a longitudinal canal running within fin bases, opening to exterior as paired pores behind each fin ray (Fig. 13). Caudal fin moderately forked, fin tips somewhat rounded. Anal fin similar in form to dorsal but lacking longitudinal canal at base. Pectoral fins inserted somewhat below mid body-depth, fin base moderately angled, fin very small and rounded, not reaching half distance from base to vent. Pelvic fin origin below pectoral fin base, fin small, triangular and partially connected to belly by membrane, folding into a distinct mid-ventral groove along belly.

Scales small and thin, cycloid, about 100 or more along lateral line, deciduous, covering trunk forward to nape, operculum scaled but head otherwise naked. Bases of dorsal, caudal and anal fins extensively scaled. Head covered with a profusion of small pores. Lateral line follows profile of back, from upper opercular opening to caudal fin base.

Two small specimens (75, 99 mm L.C.F.) are similar in general form to the above sub-adults but somewhat deeper-bodied and more compressed; all of the fins are larger, the pectoral and pelvic reaching much further than half distance from bases to vent. One specimen has the first (outer) ray of one pelvic fin much elongated (Fig. 14), a condition evident in some small Australian specimens of this species but no doubt altered in many instances during capture.

Variation: Morphometric and meristic: See Table 2.

Colour: I have not seen fresh specimens, but one small example (75 mm L.C.F. — AIM AF 403) has "Bright silver with spots and bars, azure blue" written on the label. Maul (1964: 95) described it as having "conspicuous blackish blotches arranged in irregular cross bands".

In preservative the two adults are uniform dull brown without distinctive markings, the dorsal and anal fins somewhat darker. A small juvenile, 28 mm L.C.F., taken in New South Wales waters, has a series of dark and pale vertical bars. Somewhat larger specimens are a dull grey-brown with a reticulum of dark and pale brown patches or blotches on the trunk and spreading onto the unpaired fins (Fig. 14).

Size: The largest known specimens of this species, obviously small adults, are the two specimens described here, 275 and 280 mm L.C.F. Otherwise only small juveniles are known.

Growth: The two large specimens differ from the juveniles both in form and coloration, probably indicating substantial changes in habitat with growth. The larger fish are a little thicker-bodied and have much smaller fins as well as lacking the blotched coloration on the trunk.

Distribution: *S. marmoratus* Kner and Steindachner (a junior synonym of *S. maculatus*) was described from "Sudsee", which Haedrich (1967: 62) interpreted as "presumably near Australia". Certainly the species occurs in eastern Australian waters. Allen *et al.* (1976: 435) recorded it from Lord Howe Island, and Ahlstrom *et al.* (1976: 322) from the "central water mass of the South Pacific", suggesting that it "may prove to have a circum-global distribution in the southern ocean". Fowler (1936) described its distribution as "Pelagic in the warmer Atlantic and Indo-Pacific". In New Zealand it has been taken

from off Whangarei Heads, Northland, from near Mount Maunganui, Bay of Plenty (juveniles), and from over deep water north and northwest of Raoul Island, Kermadec Islands.

The apparent rareness of this species probably indicates that it is an oceanic-pelagic species found in and over deep water. Maul (1964) and Ahlstrom *et al.* (1976) reported taking small juveniles with dip nets under jellyfish, as is characteristic of small stromateoids. The two New Zealand adults were taken at depths in excess of 300 m, in mid-ocean waters more than 1700 m deep, suggesting a movement during growth from the surface to deeper waters.

Ichthyos Jordan and Gilbert

Ichthyos Jordan and Gilbert, 1880: 305 (type species *Ichthyos lockingtoni* Jordan and Gilbert, 1880: 305, by original designation).

Parin and Permitin (1969) have described the genus *Pseudoichthyos* for the Southern Pacific form *Ichthyos australis* Haedrich (1966), but neither Krefft (1969) nor Haedrich and Horn (1972) have accepted the new genus. I follow these authors, considering that the broad relationships of these strange centrolophid fishes are poorly understood and that the situation is not helped by the proliferation of monotypic genera.

Generic diagnosis: Elongate, thin and flexible-bodied centrolophid fishes in which the dorsal fin is continuous, with short, soft, flexible spines grading into longer branched rays, the fin being very low anteriorly, originating well behind the pectoral fins. Pelvic fin insertion below pectoral fin bases. Lateral line arches a little above pectoral fins but descends to mid-lateral and runs about straight from a little behind anal fin origin; scales present on cheeks and forward between eyes; vomer, palate, tongue and basibranchials toothless. Vertebrae 49-60.

Two species of *Ichthyos* are recognised, one from the North Pacific, the other widely distributed in southern cool temperate areas, including New Zealand waters, from where it was first described.

Ichthyos australis Haedrich (Figs. 15, 16)

Ichthyos australis Haedrich, 1966: 201 (holotype: ZMC not seen; type locality: "Dana Station 3644 I, 44° 39'S, 173° 40'E," east of New Zealand (not west as noted by Haedrich, 1966: 199)); Ahlstrom *et al.*, 1976: 313; Haedrich and Horn, 1972: 29; Krefft, 1969: 4; Permitin, 1969: 178. *Pseudoichthyos australis*: Parin and Permitin, 1969: 789; Gavrilov, 1979: 146.

Ichthyos australis is recognised from New Zealand waters on the basis of a juvenile collected by the *Dana* expedition in 1928-29 (and which remained unrecognised until 1966), and an additional small adult taken to the southeast of Stewart Island in 1979. No further specimens are known from the New Zealand region. Inclusion of the species in this review is based on these records, but description is in part from material collected in the South Atlantic. No taxonomic problems are yet evident apart from the question, not addressed here, of the generic separation of the northern and southern forms of *Ichthyos*.

Common name: None.

Distinguishing characters: Distinguished from most New Zealand centrolophids by the thin, flexible, soft-bodied form, thereby resembling *Schedophilus* and *Tubbia*. It differs from both of these in having the dorsal fin origin well behind the pectoral fin bases. The very high vertebral count (49-51) is distinctive, as are the tubular laterosensory pores on the snout and interorbital.

Description: Trunk of moderate depth, thin and flexible, back and belly not greatly arched, greatest depth at about mid-abdomen. Belly in cross-section tapering to a thin, but soft ventral keel. Caudal peduncle of moderate length, thin. Head of moderate size, thin and deep. Eye small to moderate, set well down in head, interorbital convex. Snout short, bluntly rounded. Mouth of moderate size, jaws about equal, mouth slightly overhung by snout, cleft slightly oblique, reaching to about anterior third of eye. Lips firm. (Form of nostrils not clearly evident in study material owing to erosion of snout.) Lower edge of preoperculum free, finely denticulate; operculum with a weak, flat spine above pectoral fin base, bone finely serrate on lower edge. Teeth present on

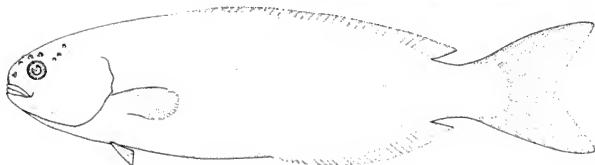


Fig. 15—*Ichthyothorax australis* Haedrich, 324 mm L.C.F. (ISH 22/76).

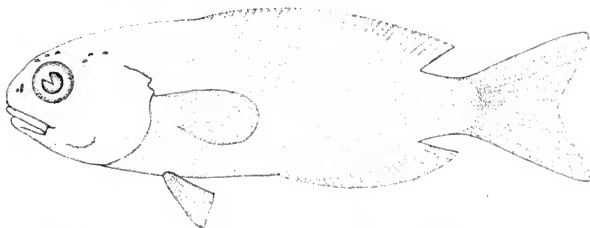


Fig. 16—*Ichthyothorax australis* Haedrich, juvenile 69 mm L.C.F. (ISH 170/76).

premaxilla and dentary, very small, even, cardiform. No teeth on vomer, palatine, pterygoids, basihyal or basibranchials. Gill openings extensive, opercular membrane not joined to isthmus. Gill rakers of moderate length, stout, toothed on inner margins. Pyloric caeca very numerous, branching.

Unpaired fins low. Dorsal fin continuous, with short, soft, flexible, spines grading into longer branched rays, rising slowly on back well behind pectoral fin base, margin of fin slightly convex, fin thick and fleshy at base, but becoming thin and membranous distally. Caudal fin well-forked, fin tips bluntly pointed. Anal fin similar in form to dorsal. Pectoral fin inserted at about mid body depth, at about level of mouth, fin base quite sharply angled, fin very small reaching about one third distance to vent, soft and rather membranous with weak rays, rounded in shape. Pelvic fin very small, almost vestigial, no membranous connection to belly evident.

Scales cycloid, thin, deciduous and very small, covering trunk forward on head and on to snout, on opercula and cheeks, and spreading out on to all fin bases. Head and trunk covered with a profusion of fine pores, sub-dermal mucosal system well developed. Also a series of larger, tubular laterosensory pores on upper head (Fig. 15). Lateral line runs almost straight from upper opercular angle to tail base.

Variation: Morphometric and meristic: See Table 2.

Colour: Fresh colour unknown. Preserved specimens (in alcohol) are a dull brown, the fins distinctly darker brown to almost black, the opercular margin and lips also dark brown; otherwise no distinctive markings.

Size: A specimen in the Institut für Seefischerei, Hamburg, is 810 mm long and another "c.a. 600 mm". Specimens between 300 and 400 mm are well represented.

Growth: The meagre material available suggests that allometry may be less evident in *I. australis* than in some other centrolophids. Compared with other species the juveniles are quite slender and elongate (Fig. 16). The fins of juveniles are more expansive.

Distribution: In the New Zealand area *I. australis* is known off the Canterbury coast and to the southeast of Stewart Island. Several specimens from the New Zealand area, identified as "*I. australis*", and supplied to me by the Japanese Far Seas Fishery Agency, proved to be examples of *Tubbia tasmanica* Whitley, a similar and related form

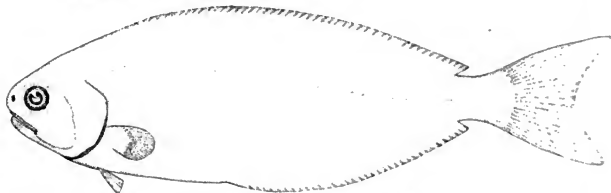


Fig. 17—*Tubbia tasmanica* Whitley, 406 mm L.C.F. (NMW 7614)



Fig. 18—*Tubbia tasmanica* Whitley, large juvenile, 133 mm L.C.F. (NMW 7613).

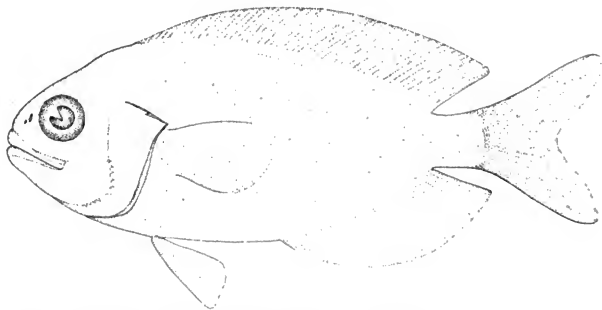


Fig. 19—*Tubbia tasmanica* Whitley, small juvenile, 68 L.C.F. (NMW 7612)

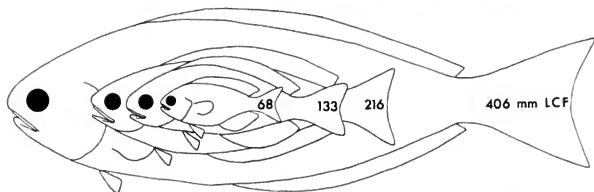


Fig. 20—*Tubbia tasmanica* Whitley, outlines of fish 68, 133, 216, and 406 mm L.C.F. showing allometry, particularly of body depth, eye size and fin dimensions.

(McDowall, 1979). Otherwise *I. australis* is known from seas off Tasmania (T.M.H. D1651), the south Atlantic and sub-Antarctic (Permitin, 1969; Parin and Permitin, 1969; Krefft, 1969), and southwestern Pacific (Gavrilov, 1979). Gavrilov suggested wide southern circumpolar distribution.

Few specimens of this species are known — the holotype, one additional New Zealand specimen, five reported from Russian expeditions to the South Atlantic (Parin and Permitin, 1969; Permitin, 1969) and 44 in the collections of the Institut für Seefischerei, Hamburg. Obviously little can be ascertained from the small amount of material available but some inferences may be made. Most specimens taken by German expeditions, both juvenile and adult, have been taken in deep to very deep waters, 600–1000 m, one down at 2000 m, and in very cold waters (2.5–3.7°C). One specimen was taken at 200 m (I.S.H. data). The Russian data show juveniles taken at moderate depths (179–325 m) (Permitin, 1969; Parin and Permitin, 1969), but their two larger specimens (267, 239 mm) were taken at the surface, over very deep water (4200 and 2000 m) and again in cold waters (1.14–5.73°C). The holotype — a small juvenile — was taken at night in a net with 1000 m of wire out and so presumably at a considerable depth. These data suggest that *I. australis* is largely a species of deep and cold waters. The statement of Permitin (1969) that *I. australis* is a “moderately warm-water species” seems unsupported by any published data. His statement that “it is thought that the spawning and development grounds of its area are distinct” is also without obvious data to support it. His conclusion that “the species multiplies in the warm sub-antarctic waters of the southern hemisphere, apparently on the shelf, close to the shores, and it grows in the waters of Antarctica” appears to be largely conjectural.

Tubbia Whitley

Tubbia Whitley, 1943 (type species: *Tubbia tasmanica* Whitley, 1943, by original designation).

Problems related to the generic taxonomy of *Tubbia* were discussed by McDowall (1979) who suggested close relationship to *Schedophilus* and *Ichthyos*. The distinct genus was retained on the grounds that the way the predorsal bones and pterygiophores interdigitate is distinctive (Ahlstrom *et al.*, 1976). These authors believed that “*Tubbia* almost certainly is a distinct monotypic genus in the family Centrolophidae, perhaps most closely allied to *Schedophilus*”. It is considered that “until *Schedophilus* is better defined and interrelationships of the species better understood, it seems appropriate to retain the genus *Tubbia*” (McDowall, 1979: 736). Generic diagnosis: Essentially like *Schedophilus*, elongate thin and flexible-bodied; 43–45 vertebrae. As the genus *Tubbia* is monotypic a full generic diagnosis would be redundant.

Tubbia tasmanica Whitley (Figs. 17–20)

Schedophilus medusophagus: Smith, 1934: 95 (not *S. medusophagus* Cocco, 1839).

Tubbia tasmanica Whitley, 1943: 179 (holotype: AMS IB1148, seen; type locality: off eastern Tasmania, 42° 41' S, 148° 34' E, between 50 m and the surface); Ahlstrom *et al.*, 1976: 298; McDowall, 1979: 736.

Schedophilus huttoni: Haedrich, 1967: 62 (partim)?

Problems in the taxonomy of *T. tasmanica* were discussed by McDowall (1979). Since that publication *T. tasmanica* has been collected widely although in small numbers from the New Zealand region.

Diagnosis: A compressed elongate centrolophid fish with dorsal fin origin above pectoral fin bases; single long, low dorsal fin; very reduced pelvic fins; closely resembling other centrolophid fishes, particularly *Schedophilus* species, from which it can be distinguished by its vertebral count of 43-45. The oblique linear rows of small pores along the dorsal and anal fin bases seem distinctive and facilitate identification.

Description: Body elongate oval; trunk of moderate depth, greatest depth just in front of vent, tapering to short caudal peduncle; peduncle somewhat longer than deep; body very compressed throughout. Head of moderate size, very deep and compressed. Eye large, well below upper head profile, interorbital narrow and convex. Snout very blunt and rounded, slightly overhanging mouth; mouth of moderate size; jaws about equal; cleft of mouth slightly oblique, reaching back to below about middle of eye; lips firm. Anterior nostril and simple aperture, posterior one an oval slit; nostrils close together and about equidistant from tip of snout and anterior margin of eye. Edge of preoperculum free, spiny; operculum with two very weak flat spines above pectoral fin base.

Teeth on premaxilla and dentary fine, uniserial and slightly separated; no teeth on vomer, palatine, pterygoids, basihyal or basibranchials, but roof of mouth and tongue covered with numerous fine, superficially tooth-like papillae. Gill openings extensive, opercular membranes not joined to isthmus. Gill rakers of moderate length, stout, toothed on inner margins.

Unpaired fins strongly developed although low. Dorsal fin very low anteriorly with short soft spines, grading into increasingly long soft rays, fin remaining low; fin base grading into body, heavily sheathed with thick skin and scales, base line thus very indistinct (counting of fin elements is both difficult and uncertain). Caudal fin small, forked, fin tips pointed, base scaled. Anal fin similar in form to dorsal fin, origin at about mid-body length. Pectoral fin insertion low, base well below mid-body depth, fin base relatively broad, vertical; fin very small, paddle-shaped, not reaching $\frac{2}{3}$ distance to vent. Pelvic fin inserted directly below pectoral base, very reduced, little more than a vestige; folding into distinct groove on mid-ventral abdomen; no membranous attachment to belly.

Scales very small, about 120 along lateral line; cycloid, deciduous, extending over bases of dorsal, caudal and anal fins; head, including opercles, preopercles, chin, nape and snout extensively covered with scales. Lateral line arching upwards from upper opercular opening, curving down again below dorsal fin origin and more or less following back profile to base of tail, slightly undulatory above vent. Pores very numerous, particularly on snout, around eyes and mouth and on chin; a broad band of pores along back below dorsal fin, a similar band above anal fin base; pores along fin bases in distinct, oblique rows of about 8-10 pores each. Pyloric caeca numerous, simple, finger-like.

Variation: Morphometric and meristic: See Table 2.

Colour: Rather uniform dull brownish without distinctive markings. Dorsal and anal fins darker chocolate brown, also opercular membrane; snout and opercles a little paler. Little colour change in preservative. Whitley (1943) described the small juvenile holotype (72.5 mm) as "Dorsally and laterally pale mauve, fading to silver below, spots on head silver. Fins slightly darker than body". In alcohol, New Zealand juvenile of 116 mm dull, unmarked greyish-brown, a little darker on back, dorsal and anal fins dark grey. Juveniles, 57 mm and 70.5 mm, light brownish on head and back down to lateral line; below this peppered with many small round spots; dorsal, anal and pelvic fins brown, contrasting with colour of trunk.

Size: Known to reach 450 mm L.C.F. (407 mm S.L.).

Growth: Shape changes greatly with growth, as can be seen from comparisons of body proportions in Table 2 (Fig. 20). In particular, the body becomes more elongate with growth, the head relatively much shorter, and, as a result, predorsal and preanal dimensions also show relative decreases. The size of the pectoral and pelvic fins is also relatively much smaller in large specimens. Although not evident in Table 2, the relative heights of the dorsal and anal fins also decrease markedly with growth.

Distribution: Known from off eastern Tasmania, and off the Natal coast of South Africa. In New Zealand it occurs off the southwestern coast of South Island on the southern Campbell Plateau, to the south of New Zealand and northeast of the Chatham Islands (Fig. 8). *T. tasmanica* is possibly of general distribution in southern cool-temperate to subantarctic waters.

The smallest specimen (57 mm) was taken inshore at the surface, the intermediate ones offshore in deeper waters, the largest ones (373, 402, 406 mm) in bottom trawls at 775-800 m. This suggests that with growth *T. tasmanica* moves offshore and descends to greater depths, the adults living in deep waters.

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REFERENCES

- Ahlstrom, E. H.; J. L. Butler; B. Y. Sumida 1976. Pelagic stromateoid fishes (Pisces: Perciformes) of the eastern Pacific: Kinds, distributions and early life histories and observations on five of these from the northwest Atlantic. *Bulletin of Marine Science* 26(3): 285-402.
- Allen, G. R.; D. F. Hoese; J. R. Paxton; J. E. Randall; B. C. Russell; W. A. Starck; F. H. Talbot; G. P. Whitley 1976. Annotated checklist of the fishes of Lord Howe Island. *Records of the Australian Museum* 30(15): 365-454.
- Atchley, A. A. 1967. Fishes of the San Juan Fernandez Island. Typed manuscript in Fisheries Research Division, Christchurch. 14 pp.
- Benham, W. B. 1934. (Annual Report on the Portobello Marine Fish Hatchery and Biological Station). *N.Z. Marine Department Annual Report on Fisheries 1933-34*: 29-31.
- 1935. (Annual Report on the Portobello Marine Fish Hatchery and Biological Station). *N.Z. Marine Department Annual Report on Fisheries 1934-35*: 20-22.
- 1938. (Annual Report on the Portobello Marine Fish Hatchery and Biological Station). *N.Z. Marine Department Annual Report on Fisheries 1937-38*: 56-58.
- Bloch, M. E., and J. G. Schneider 1801. *Systema ichthyologicae iconibus ex illustratum. Post orbitus auctoris opus inchoatum absoluti, correxit, interpolavit*. Schneider: Berlin. 548 pp.
- Buck, P. H. 1926. The Maori craft of netting. *Transactions and Proceedings of the N.Z. Institute* 50: 597-646.
- Carmichael, D. 1818. Some account of the Island of Tristan da Cunha and of its natural productions. *Transactions of the Linnaean Society, London* 12: 483-513.
- Castelnau, F. de 1872. Contributions to the ichthyology of Australia. *Proceedings of the Zoological and Acclimatisation Society of Victoria* 1: 29-247.
- Chirichigno, N. 1974. Clave para identificar los peces marinos del Peru. *Instituto del Mar del Peru Informe* 44: 1-387.
- Cocco, A. 1839. Sopra un nuova genere di pesci dello famiglia de Centrolofini e di una nuove species di *Trachurus*. *Innominata Messina* 3(7): 56-59.
- Craddock, J. E., and G. W. Mead 1970. Midwater fishes from the eastern South Pacific. Scientific results of the Southeast Pacific Expedition. *Anton Bruun Report* 3: 3.1-3.46.
- Cuvier, G., and A. Valenciennes 1833. *Histoire naturelle des poissons*. Vol. 9. Levrault, Paris. 512 pp.
- Doogue, R. B., and J. M. Moreland 1961. *New Zealand Sea Anglers' Guide*. Reed: Wellington. 318 pp. 2nd edition.

- Eggleston, D. A. 1975. New warehouse species discovered. *Catch* 2(2): 7.
- Forster, J. R. 1872. Tagebuch ein der Reise nach Neu-Sudwalliserstem Wundertze der in Port Jackson angelegten neuen Kilonie (J. White). *Magazine von merkwürdigen neuen Reisebeschreibungen* 9: 1-287.
- 1874. *Descriptions animalium*. Lichenstein, Berlin. 424 pp.
- Fowler, H. W. 1936. The marine fishes of West Africa based on the collection of the American Museum Congo Expedition, 1909-1915. *Bulletin of the American Museum of Natural History* 60(2): 609-1493.
- 1940. The fishes obtained by the Wilkes expedition 1838-1842. *Proceedings of the American Philosophical Society* 82: 733-800.
- Francis, R. C., and K. A. Fisher 1979. Assessment of the deepwater fish resources of the New Zealand area. *N.Z. Ministry of Agriculture and Fisheries, Fisheries Research Division Occasional Publication* 21: 1-30.
- Gavrilov, G. M. 1973. A new species of the genus *Seriotelella* on the New Zealand plateau. *Journal of Ichthyology* 13(5): 631-640.
- 1979. A new find of *Pseudocichthys australis* in the Antarctic region of the southwest Pacific. *Journal of Ichthyology* 19(5): 146-148.
- Gavrilov, G. M., and N. P. Markina 1979. The feeding ecology of fishes of the genus *Seriotelella* (fam. Nomeidae) on the New Zealand plateau. *Journal of Ichthyology* 19(6): 128-135.
- Gill, T. 1893. A comparison of antipodal faunas. *Memoirs of the National Academy of Sciences* 6: 91-124.
- Gmelin, J. F. 1789. *Systema Naturae*. Gmelin, Lipsiae. 3 vols. 13th edition.
- Graham, D. H. 1938. Fishes of Otago Harbour and adjacent seas with additions to previous records. *Transactions and Proceedings of the Royal Society of N.Z.* 68(3): 399-419.
- 1939. Breeding habits of the fishes of Otago Harbour and adjacent seas. *Transactions and Proceedings of the Royal Society of N.Z.* 69(3): 361-372.
- 1953. *A treasury of New Zealand fishes*. Reed, Wellington. 404 pp.
- 1956. *A treasury of New Zealand fishes*. Reed, Wellington. 424 pp. 2nd edition.
- Graham, J. 1963. The North Otago shelf fauna. Part III. Chordata, sub-phylum Gnathostomata. *Transactions of the Royal Society of N.Z., Zoology* 3(16): 165-170.
- Griffin, L. T. 1928. Studies in New Zealand fishes. *Transactions and Proceedings of the N.Z. Institute* 59: 374-388.
- Grimes, P. J., and D. A. Robertson 1981. Eggs and larval development of the silver warehouse (Pisces: Centrolophidae). *N.Z. Journal of Marine and Freshwater Research* 15(3): 261-266.
- Guichenot, A. 1848. Peces de Chile. In C. Gay, *Historia fisico y politico de Chile, Zoologia* 2: 137-370.
- Günther, A. 1859. *Catalogue of the Acanthopterygian fishes in the Collection of the British Museum*. Vol. 1. Taylor and Frances: London. 524 pp.
- 1860. *Catalogue of the Acanthopterygian Fishes in the Collection of the British Museum*. Vol. 2. Taylor and Frances: London. 548 pp.
- Haedrich, R. L. 1966. The stromateoid fish genus *Icichthys*: Notes and a new species. *Videnskabelige Meddelelser Danske Naturhistorisk Forening* 129: 199-213.
- 1967. The stromateoid fishes: systematics and a classification. *Bulletin of the Museum of Comparative Zoology Harvard University* 135(2): 31-139.
- Haedrich, R. L., and M. H. Horn 1972. A key to the stromateoid fishes. *Woods Hole Oceanographic Institution Technical Report WHOI-72-15*: 1-46.
- Haedrich, R. L., and J. G. Nielsen 1966. Fishes eaten by *Alepisaurus* (Pisces, Iniomi) in the southeastern Pacific Ocean. *Deep Sea Research* 13: 909-919.
- Heath, E., and J. M. Moreland 1967. *Marine Fishes of New Zealand*. Reed: Wellington 56 pp.
- Hector, J. 1884. The fisheries of New Zealand. *Bulletin of the U.S. Fisheries Commission* 4: 53-55.
- Hefford, A. E. 1936. New Zealand fishes and fisheries. In *Handbook for New Zealand*. Australian and New Zealand Association for the Advancement of Science (Prepared for Auckland meeting, January 1937), pp. 71-77. Government Printer: Wellington.
- Hewitt, G. C. 1963. Some New Zealand parasitic copepoda of the family Caligidae. *Transactions of the Royal Society of N.Z. Zoology* 4(3): 61-115.

- 1968. Some New Zealand parasitic copepoda of the family Anthosomidae. *Zoology Publications from Victoria University of Wellington* 47: 1-31.
- Hubbs, C. L., and K. F. Lagler 1958. *Fishes of the Great Lakes Region*. University of Michigan: Ann Arbor. 213 pp.
- Hutton, F. W. 1872. Catalogue with diagnoses of the species. In F. W. Hutton, J. Hector, *Fishes of New Zealand*. Colonial Museum and Geological Survey. Wellington. Pp. 1-93.
- 1873. Contributions to the ichthyology of New Zealand. *Transactions and Proceedings of the N.Z. Institute* 6: 259-272.
- 1875. Fauna of Otago. In F. W. Hutton, G. H. F. Ulrich, *Report of the Geology and Gold Fields of Otago*. Appendix C. to Part 1. Geology of Otago. Provincial Council of Otago: Dunedin. Pp. 128-139.
- 1876. Contributions to the ichthyology of New Zealand. *Transactions and Proceedings of the N.Z. Institute* 9: 209-218.
- 1890. List of the New Zealand fishes. *Transactions and Proceedings of the N.Z. Institute* 22: 275-285.
- 1896. Notes on New Zealand fishes with description of a new species. *Transactions and Proceedings of the N.Z. Institute* 28: 314-318.
- 1904a. *Index Faunae Novae Zealandiae*. Dulau: London. 372 pp.
- 1904b. On the occurrence of *Centrolophus* in New Zealand. *Transactions and Proceedings of the N.Z. Institute* 36: 149-150.
- Jordan, D. S. 1923. A classification of fishes including families and genera as far as known. *Stanford University Publications, University Series, Biological Science* 3(2): 77-243.
- Jordan, D. S., and C. H. Gilbert 1880. Description of a new species of deep water fish (*Ichthyos lockingtoni*) from the coast of California. *Proceedings of the U.S. National Museum* 3: 305-308.
- Kaberry, A. C. 1957. Sea fisheries. In F. R. Callaghan (Ed.), *Science in New Zealand*. Handbook for the 1957 ANZAAS Conference. Reed: Wellington. Pp. 85-96.
- Karrer, C. 1973. Über Fische aus dem Südatlantik. *Mitteilungen Zoologisches Museum, Berlin* 49(1): 189-257.
- Kner, R., and F. Steindachner 1866. Neue Fische aus dem Museum der Herren Joh. C. Godeffroy und Sohn, in Hamburg. *Sitzungsberichte aus dem Akademie des Wissenschaft, Wien* (1), 54(8): 356-395.
- Kreffl, F. 1969. Ergebnisse der Forschungsreisen des FFS "Walther Herwig" nach Süd Amerika. VI. Fische der Familie Centrolophidae (Perciformes, Stromateoidei). *Archiv für Fischereiwissenschaft* 20: 1-9.
- Lacépède, B. G. 1803. *Historie Naturelle des Poissons*. Vol. IV. 360 pp.
- McAllister, D. E., and J. A. Randall 1975. A new species of centrolophid fish from Easter Island and Rapa Iti Island in the South Pacific. *National Museum of Canada Publications in Biological Oceanography* 8: 1-7.
- McCulloch, A. R. 1914. Report on some fishes obtained by the F.I.S. *Endeavour* on the coasts of Queensland, New South Wales, Victoria, South Australia and Tasmania. Part 2. *Zoological results of the fishing experiments carried on by F.I.S. Endeavour 1909-10, under H. C. Dannevig, Commonwealth of Fisheries* 2: 75-165.
- McDowall, R. M. 1976. The status of *Stromateus maculatus* Forster — a fish from New South Wales. *Journal of the Royal Society of N.Z.* 6(4): 489-491.
- 1979. The centrolophid genus *Tubbia* (Pisces: Stromateoidei). *Copeia* 1979(4): 733-738.
- 1980a. *Seriotele caerulea* Guichenot (1848) in New Zealand waters (Stromateoidei: Centrolophidae). *Journal of the Royal Society of N.Z.* 10(1): 65-74.
- 1980b. First adults of *Schedophilus maculatus* Günther 1860 (Stromateoidei: Centrolophidae). *Journal of the Royal Society of N.Z.* 10(2): 141-151.
- 1980c. Juvenile white warehou. *Catch* 7(7): 6.
- 1981. A sub-dorsal fin pore-canal system in *Schedophilus maculatus* (Stromateoidei: Centrolophidae). *Copeia* 1981(2): 492-494.
- Macleay, W. 1881. Descriptive catalogue of the fishes of Australia. Part 2. *Proceedings of the Linnean Society of New South Wales* 5: 510-629.

- McLintock, A. H. 1966. Fauna and flora. European, Maori and scientific names of some common New Zealand fauna and flora. In A. H. McIntock (Ed.), *An Encyclopedia of New Zealand* 3: 705-712. Government Printer: Wellington. 3 vols.
- Manter, H. W. 1954. Some digenetic trematodes from fishes of New Zealand. *Transactions of the Royal Society of N.Z.* 82: 475-568.
- Maul, G. E. 1964. Observations on young live *Mupus maculatus* (Gunther) and *Mupus ovalis* (Valenciennes). *Copeia* 1964(1): 93-97.
- Moreland, J. M. 1963. *Native Sea Fishes*. Reed: Wellington. 64 pp.
- Morton, A. 1888. Description of two new fishes. *Papers and Proceedings of the Royal Society of Tasmania, 1887*: 77-78.
- Norman, J. R. 1935. Coast fishes. Part I. The South Atlantic. *Discovery Report* 12: 1-58.
- 1937. Coast Fishes. Part II. The Patagonian region. *Discovery Reports* 16: 1-150.
- Ogilby, J. D. 1893. Description of a new fish from New Zealand. *Records of the Australian Museum* 2(5): 64-65.
- Parin, N. V. 1958. Rare pelagic fishes of the northwestern Pacific (*Taractes steindachneri*, *Palinurichthys japonicus* and *Centrolophus lockingtoni*). *Problems in Ichthyology* 12: 162-170.
- Parin, N. V., and Y. Y. Perminin. 1969. Materials on the pelagic fish fauna of the Antarctic. A new genus of stomateoid fishes — *Pseudocichthys* (Pisces: Centrolophidae). *Journal of Ichthyology* 9: 789-794.
- Parrott, A. W. 1957. *Sea Anglers' Fishes of New Zealand*. Hodder and Stoughton: London. 176 pp.
- Patchell, G. J. 1979. A preliminary analysis of the west coast South Island deep water fishery. Pp. 42-46 in Prospects and problems for New Zealand's demersal fishermen. Proceedings of the Demersal Fisheries Conference, October 1978. N.Z. Ministry of Agriculture and Fisheries, Fisheries Research Division Occasional Publication 19: 1-123.
- Paul, L. J. 1966. Warehouse. In A. H. McIntock (Ed.), *An Encyclopedia of New Zealand*. Government Printer: Wellington. 3 vols.
- 1978. Fish species of the E.E.Z. *Catch* 5(2): 12-13.
- 1979. Deep water fish resources off the southeast coast of New Zealand. Pp 52-46 in Prospects and problems for New Zealand's demersal fisheries. Proceedings of the Demersal Fisheries Conference, October 1978. N.Z. Ministry of Agriculture and Fisheries, Fisheries Research Division Occasional Publication 19: 1-123.
- 1980a. Warehouse — facts and figures. *Catch* 7(7): 5.
- 1980b. Identification of warehouse. *Catch* 7(7): 5-6.
- Paul, L. J., and M. W. Cawthorn 1977. Data analyses shows distribution pattern of deep water fishes. *Catch* 4(3): 3.
- Paul, L. J., and D. A. Robertson 1979. Appendix — Species composition of the demersal fish resource. Pp 117-123 in Prospects and problems for New Zealand's demersal fisheries. Proceedings of the Demersal Fisheries Conference, October 1978. N.Z. Ministry of Agriculture and Fisheries, Fisheries Research Division Occasional Publication 19: 1-123.
- Perminin, Y.Y. 1969. New data on species composition and distribution of fishes in the Scotia Sea, Antarctica. (Second communication). *Journal of Ichthyology* 9: 167-181.
- Phillipps, W. J. 1918. Edible fishes of Wellington. *N.Z. Journal of Science and Technology* 1: 268-271.
- 1921. Notes on the edible fishes of New Zealand. With a record of fishes exposed for sale in Wellington during 1918. *N.Z. Journal of Science and Technology* 4: 114-125.
- 1927a. A checklist of the fishes of New Zealand. *Journal of the Pan-Pacific Research Institution* 2(1): 9-15.
- 1927b. Bibliography of New Zealand fishes. *N.Z. Marine Department Fisheries Bulletin* 1: 1-68.
- 1947. A list of Maori fish names. *Journal of the Polynesian Society* 56: 41-51.
- 1948. Fishes taken in Wellington harbour. *Pacific Science* 2: 128-130.
- 1949. *Native Fishes*. Reed: Wellington. 60 pp.
- Phillipps, W. J. and E. R. Hodgkinson 1922. Further notes on the edible fishes of New Zealand. *N.Z. Journal of Science and Technology* 5(12): 91-97.
- Powell, A. W. B. 1941. Biological primary types in the Auckland Museum. *Records of the Auckland Institute and Museum* 2: 151-156.

- Regan, C. T. 1902. A revision of the fishes of the family Stromateidae. *Annals and Magazine of Natural History* (7)10 115-131, 194-207.
- 1914. Fishes. *British Antarctic* ("Terra Nova") *Expedition 1910 Zoology* 1: 1-54.
- 1916. Larval and post-larval fishes. *British Antarctic* ("Terra Nova") *Expedition 1910 Zoology* 1: 125-152.
- Richardson, J. 1948. Ichthyology. In J. Richardson, J. Gray, *The Zoology of the Voyage of H.M.S. Erebus and Terror during the Years 1838-43*. London. 139 pp.
- Robertson, D. A. 1975. A key to the planktonic eggs of some New Zealand marine teleosts. *N.Z. Ministry of Agriculture and Fisheries, Fisheries Research Division Occasional Publication* 9: 1-19.
- 1980. Hydrology and the quantitative distribution of planktonic eggs of some marine fishes of the Otago coast, southeastern New Zealand. *N.Z. Ministry of Agriculture and Fisheries Fisheries Research Bulletin* 21: 1-69.
- Scott, T. D., C. J. M. Glover, R. V. Southcott. 1975. *The Marine and Freshwater Fishes of South Australia*. Government Printer: Adelaide. 392 pp.
- Sherrin, R. A. A. 1886. *Handbook of the Fishes of New Zealand*. Wilson and Horton: Auckland. 307 pp.
- Smith, J. L. B. 1934. Marine fish of seven genera new to South Africa. *Transactions of the Royal Society of South Africa* 22: 89-100.
- 1966a. The rare northeastern Atlantic fish, *Centrolophus britannicus* in South Africa. *Annals and Magazine of Natural History* (13), 8: 505-509.
- 1966b. A new stromateoid fish from South Africa with illustration of the unique rare *Centrolophus huttoni* Waite, 1910. *Annals and Magazine of Natural History* (13), 9: 1-3.
- Stehman, M. von, and W. Lenz. 1973. Ergebnisse der Forschungsreisen des FFS "Walther Herwig" nach Sudamerika. XXVI. Systematik und Verbreitung der Artengruppe — *Seriola punctata* (Schneider, 1801), *S. porosa* Guichenot, 1848, *S. doubla* (Günther, 1869) — sowie taxonomische Bemerkungen zu *Hyperoglyphe* Günther, 1859 und *Schedophilus Cocco*, 1839 (Osteichthyes, Stromateoidei, Centrolophidae). *Archiv für Fischereiwissenschaft* 23(3): 179-201.
- Struik, G. J., and J. R. Bray. 1979. A fish survey in a Marlborough sounds estuary from 1971 to 1978. *N.Z. Journal of Ecology* 2: 30-33.
- Thomson, G. M. 1892. Notes on sea fishes. *Transactions and Proceedings of the N.Z. Institute* 24: 202-215.
- 1906. The Portobello Marine Fish Hatchery and Biological Station. *Transactions and Proceedings of the N.Z. Institute* 38: 529-558.
- 1913. The natural history of Otago Harbour and the adjacent sea, together with a record of the researches carried on at the Portobello Marine Fish Hatchery. Part I. *Transactions and Proceedings of the N.Z. Institute* 45: 225-251.
- 1926. (Annual report of the Portobello Marine Fish Hatchery and Biological Station). *N.Z. Marine Department Report on Fisheries for the Year 1925-26*: 18-19.
- Thomson, G. M., and T. Anderton. 1921. History of the Portobello marine fish hatchery and biological station. *Bulletin of N.Z. Board of Sciences and Arts* 2: 1-131.
- Thomson, G. S., and G. M. Thomson. 1923. The economic value of whalefeed. *N.Z. Journal of Science and Technology* 6: 111-114.
- Thomson, P. 1879. Our fish supply. *Transactions and Proceedings of the N.Z. Institute* 4: 219-223.
- Tong, L. J., and R. D. Elder. 1968. Distribution and abundance of demersal fish from trawl stations in the Bay of Plenty, New Zealand, 1961-63. *N.Z. Journal of Marine and Freshwater Research* 2(1): 49-66.
- Trunov, I. A. 1969. *Schedophilus huttoni* (Centrolophidae) a species of fish new to the Atlantic Ocean. *Journal of Ichthyology* 9(3): 443-445.
- 1975. Notes on fishes of the suborder Stromateoidei from the southeastern Atlantic. *Journal of Ichthyology* 15(3): 351-360.
- Waite, E. R. 1894. New or rare fishes from Maroubra, N.S.W. *Proceedings of the Linnean Society of New South Wales* (2) 9: 215-227.
- 1904. Additions to the fauna of Lord Howe Island, No. 4. *Records of the Australian Museum* 5(3) 135-186.
- 1907. A basic list of the fishes of New Zealand. *Records of the Canterbury Museum* 1: 3-39.

- 1910a. A list of the known fishes of Kermadec and Norfolk Islands and a comparison with those of Lord Howe Island. *Transactions and Proceedings of the N.Z. Institute* 42: 370-383.
- 1910b. Notes on New Zealand fishes. *Transactions and Proceedings of the N.Z. Institute* 42: 384-391.
- 1911. Scientific results of the New Zealand Government Trawling Expedition 1907. Pisces. Part II. *Records of the Canterbury Museum* 1: 157-258.
- 1912a. Additions and corrections to the basic list of the fishes of New Zealand. *Records of the Canterbury Museum* 1: 313-322.
- 1912b. Notes on New Zealand fishes: No 2. *Transactions and Proceedings of the N.Z. Institute* 44: 194-202.
- Whitley, G. P. 1933. Studies in ichthyology No 7. *Records of the Australian Museum* 19(1): 60-112.
- 1943. Ichthyological notes and illustrations. (Part 2). *Australian Zoologist* 10(2): 167-187.
- 1956. Namelist of New Zealand fishes. In D. H. Graham *Treasury of New Zealand Fishes*. Reed: Wellington. 424 pp. 2nd edition. pp 397-414.
- 1968. A checklist of the fishes recorded from the New Zealand region. *Australian Zoologist* 15(1): 1-102.
- Whitley, G. P., and W. J. Phillipps. 1939. Descriptive notes on some New Zealand fishes. *Transactions of the Royal Society of N.Z.* 69: 228-236.
- Wilson, C. A. (Annual report on the portobello Marine Fish Hatchery and Biological Station). *N.Z. Marine Department Annual Report on Fisheries* 1936-37: 31-32.
- Winstanly, R. H. 1978. Food of the trevalla *Hyperoglyphe parosa* (Richardson) off southeastern Australia. *N.Z. Journal of Marine and Freshwater Research* 12(1): 78-79.

APPENDIX: Material examined

Hyperoglyphe antarctica (FRD material not retained)

- FRD: Bay of Plenty, August 1971.
 FRD: 40° 42' S × 176° 45' E 290-330 m, 26 May 1971.
 FRD: 42° 09' S × 170° 34' E, 365 m (R.V. *James Cook* station J 05/012/71)
 FRD: 40° 35' S × 176° 50' E, 290-330 m, 25 May 1971

Seriotelella punctata (FRD material not retained)

- FRD: 38° 39' S × 173° 52' E — 38° 35' S × 173° 50' E 106 m, 12 November 1971 (R.V. *James Cook* station J 16/43/71)
 FRD: 40° 18' S × 173° 47' E — 40° 15' S × 173° 46' E 86 m, 8 January 1972 (R.V. *James Cook* station J01/17/72)
 FRD: 40° 24' S × 173° 44' E — 40° 28' S × 174° 46' E 75 m, 13 May 1971 (R.V. *James Cook* station J 06/90/71)
 FRD: 40° 04' S × 173° 21' E — 39° 57' S × 173° 26' E 95-96 m, 12 May 1971 (R.V. *James Cook* station J 06/77/71)
 FRD: 43° 16' S × 174° 24' E, 485 m, 28 April 1976 (R.V. *Shinkai Maru* station SM 5)
 FRD: 43° 41' S × 174° 45' E — 43° 2' S × 173° 22' E 483 m 28 April 1976 (R.V. *Shinkai Maru* station SM2/6)
 FRD: 43° 23' S × 174° 27' E 487 m 28.4.76 (R.V. *Shinkai Maru* station SM 2/7)

Seriotelella brama (FRD material not retained):

- FRD: off Canterbury Coast, 45° 05' S × 171° 21' E — 45° 02' S × 171° 22' E, 65-67 m (R.V. *W. J. Scott* station 44/T4), 11 December 1979.
 FRD: 45° 05' S × 171° 21' E — 45° 52' S × 171° 26' E, 89-91 m (R.V. *W. J. Scott* Station 445/T4), 11 December 1979.
 FRD: 43° 44' S × 173° 13' E — 43° 47' S × 173° 11' E, 58-60 m (R.V. *W. J. Scott*, Station 489/T9), 23 January 1980.
 NMW: off Kapiti Island, 0-6 m, 20 June 1971 (gill net).

Seriotelella caerulea:

- NMW 3192: Cook Strait off Cape Campbell, 90 m, 17 June 1962.
 NMW 5813: off Auckland Islands, 51° 01' S, 166° 18' E, 507-500 m, (R.V. *James Cook* Station J 3/13/72) 21 February 1972.
 FRD: Chatham Rise, off Canterbury coast, 43° 16' S × 174° 24' E, 485 m (R.V. *Shinkai Maru* station SM 4) 28 April 1976.

- FRD: 43° 22' S × 174° 25' E, 280 m, (R.V. *Shinkai Maru* station SM 9) 29 April 1976.
 FRD: 43° 30' S × 174° 46' E, 463 m (R.V. *Shinkai Maru* station SM 14) 30 April 1976.
 FRD: 43° 46' S × 175° 10' E, 493 m (R.V. *Shinkai Maru* station SM 16) 1 June 1976.
 FRD: 43° 23' S × 174° 27' E, 487 m (R.V. *Shinkai Maru* station SM 2/7) 28 April 1976.
 FRD: 43° 12' S × 174° 18' E, ? m, (R.V. *Shinkai Maru* station SM 2/35), 6 June 1976.
 FRD: Chatham Rise, off Canterbury coast, 43° 44' S × 175° 00' E, ? m, 31 July 1975 (determined as *S. tinro* by Dr Gavrilov).

Seriola labyrinthica:

- NMW 8020: Tutukaka, near Whangarei, speared under floating debris, 15 March 1979.

Centrolophus niger:

- FRD: Hawkes Bay, line caught, no date.
 FRD: Chatham Rise, off Canterbury, precise locality unrecorded, (R.V. *Shinkai Maru*, Cruise 2, 1976).
 FRD: 43° 25' S × 174° 28' E — 43° 19' S × 174° 21' E, 486 m (R.V. *Shinkai Maru* station SM 2/11) 30 April 1976.
 FRD: 43° 23' S × 174° 27' E, 487 m (R.V. *Shinkai Maru* station SM 2/7) 28 April 1976.
 FRD: 43° 41' S × 174° 45' E — 43° 2' S × 174° 22' E, 483 m (R.V. *Shinkai Maru* station SM 2/6) 28 April 1976.
 FRD: off North Cape, 173° 10' S × 34° 25' E, over depth 120 m 10 September 1977 (R.V. *Ikatere*, surface plankton net).
 FRD: off Paxtons Point 173° 15' S × 34° 40' E, over depth 40 m 6 September 1977 (R.V. *Ikatere*, surface plankton net).
 FRD: Spirits Bay, 172° 50' S × 34° 20' E, over depth 60 m 9 September 1977 (R.V. *Ikatere*, surface plankton net).
 FRD: off Te Toti Head, 173° 10' S × 34° 30' E, over depth 80 m, 7-8 September 1977 (R.V. *Ikatere*, surface plankton net).

Schedophilus huttoni:

- CMC 134: beach cast at Sumner, near Christchurch, 16 March 1903 (holotype).
 CMC 113: beach cast at Hokitika, March 1965.
 NMW 5571: taken in shallow water, Jacksons Bay, 1 February 1972.
 NMW 9762: over Lord Howe Rise, west of New Zealand, 37° 43' S × 169° 11' E, 797-840 m, 28 January 1980 (R.V. *James Cook*, Station J 2/34/81).
 AMS 1B
 3644: taken by trawl off Montague Island, N.S.W. 36° 15' S × 115° 15' E, September 1956.
 MCZ 55142: South eastern Pacific Ocean, off Chile, 33° 20' S × 73° 41' W, 31 January — 1 February 1966 (R.V. *Anton Bruun*, Cruise XIV, coll. 50).

Schedophilus maculatus:

- NMW 7637: near Kermadec Islands, north of New Zealand, 27° 51' S × 178° 56' E to 178° 58' E, 360 m, over 1700 m, 18 June 1976 to 19 June 1976.
 NMW 4530: Mount Maunganui, 1965.
 AIM AF403: off Whangarei Heads, 10 December 1933.
 AMS 1A6535: washed ashore, Maroubra, N.S.W., Australia, 8 December 1935.

Ichthyos australis:

- ISH 170/76: South Atlantic Ocean, 43° 25' S × 49° 58' W — 43° 26' S × 49° 58' W, 600-620 m, 20 November 1975.
 ISH 222/76: 46° 44' S × 49° 59' W — 46° 46' S × 49° 59' W, 980 m, 21 November 1975.
 ISH 433/71: 38° 20' S × 54° 33' W, 1040-997 m, 5 March 1971.
 FRD: 48° 55' S × 170° 17' E, 770-795 m (F.V. *Wesermunde* station W 04/173/79) 29 September 1979.
 TMH D1651: off southeastern Tasmania 47° 09' S × 148° 10' E 2 January 1980.

Tubbia tasmanica:

- NMW 7612: Dusky Sound, 45° 45' S × 166° 37' E, at surface, 10 February 1973.
 NMW 7613: off Puysegger Point, southwestern Fiordland, 46° 20' S × 165° 31' E, 167 m over 2000 m (R.V. *James Cook* Station J 2/3/76).
 NMW 7164: Southern Campbell Plateau, 53° 26' S × 173° 10' E, 800 m.
 AMS 1B 1148: off eastern Tasmania 42° 41' S × 145° 34' E 0-50 (holotype).
 TMN D1650: off southeastern Tasmania, 47° 12' S × 148° 27' E, 15-200 m, 2 January 1980.
 RUSI 7423: off Natal.

- NMW 9648: Pukaki Rise (?), $43^{\circ}25' \text{ S} \times 174^{\circ}33' \text{ E}$, 800-810 m (F.V. *Wesermunde* Station W 04/200/79), 3 October, 1979.
- FRD — : Cook Strait, $41^{\circ}45' \text{ S} \times 174^{\circ}28' \text{ E}$, 18 m, over 112 m (R.V. *James Cook* J 19/24/78) 15 December, 1978.
- NMW 9649: South of the Campbell Rise, $48^{\circ}55' \text{ S} \times 177^{\circ}17' \text{ E}$, 770-795 m (F.V. *Wesermunde* W. 04/173/79), 26 September, 1979.

Aspects of the geology and hydrology of Nettlebed Cave, Nelson, New Zealand

Anne C. Wright*

Nettlebed Cave, Nelson, consists of several well-developed rift passages superimposed on an older, three-dimensional maze of phreatic tubes which in places is preferentially developed in the plane of transposed bedding. The cave is formed in both massive and flaggy Arthur Marble and is the result of a complex hydrological history of successive lowerings of the water table. Both bedding (transposed) and fractures (probably faults) are major geological controls of cave development.

INTRODUCTION

Nettlebed Cave and the Pearse resurgence are a continuous system (A. Cody, pers. comm.) located on the eastern side of Arthur Range, Nelson, New Zealand (Figs. 1, 2). The Pearse catchment is considered to be the eastern watershed between The Twins and Flora Saddle, including the area of the Ellis Basin where dye tracing has proved the hydrological connection between Grange Slocker and Pearse resurgence (Professor P. Williams, pers. comm.). Many shafts are known from above the bushline within the Pearse catchment area (James and Montgomery, 1971; Watson *et al.*, 1971; Newman, 1973; Shannon, 1973; Montgomery *et al.*, 1976), but few have been found within the bush, perhaps because of the hitherto limited amount of time spent prospecting the steep forested terrain.

The Pearse resurgence (S13/136378), at the head of Pearse Stream (Fig. 1), has long been known and is clearly marked on the topographical map of the area. The resurgence is a vauclusian spring with an average discharge of about 2 m³/s (Scarfe, 1972; Pugsley, 1979). Divers have penetrated about 60 m of large phreatic passage but were unable to find dry leads (Blundell, 1975). Water temperature was measured at 8.1°C in March 1971 (Cody, 1973). 'Nettlebed' is the name approved by, and registered with, the New Zealand Speleological Society (NZSS) for this cave. It is not an official geographic name. Various underground features have been named by cavers, usually the original explorers. These names appear on the NZSS map of Nettlebed (Cody, 1980), and some are described by Cody (1979).

The only known entrance to Nettlebed Cave (S13/132375) is in the usually dry bouldery bed of Eyles Creek, almost a kilometre upstream from the confluence of that stream with the main Pearse Stream, just below Pearse resurgence. This entrance was discovered during the 1969-1970 NZSS Mt Arthur Expedition (Watson *et al.*, 1971) but was not explored until the following October. Between 1971 and 1973 several trips explored, surveyed, and photographed the entrance series, including the lower level passages leading to the Midas Chambers (Cody, 1973). The entrance series comprises all passages east of Hinkle-Horn-Honking-Holes (Fig. 3). By mid-1973 surveyed passage totalled 1.3 km.

Blasting in the small passages at the top of a massive 20-m-high flowstone slope was finally successful in January 1979 (Cody, 1979), opening up the prospect of a major cave system. Eight more trips during that year explored and surveyed Portalverst, Oubliette — Reprieve Alley, lower Poms Progress — Spillway, and Caecumslither, culminating in October in the discovery of a large waterfall chamber, now called Jacobs Well (Fig. 3). The climbing of the 53-m-high waterfall in Jacobs Well during the 1979-1980 NZSS

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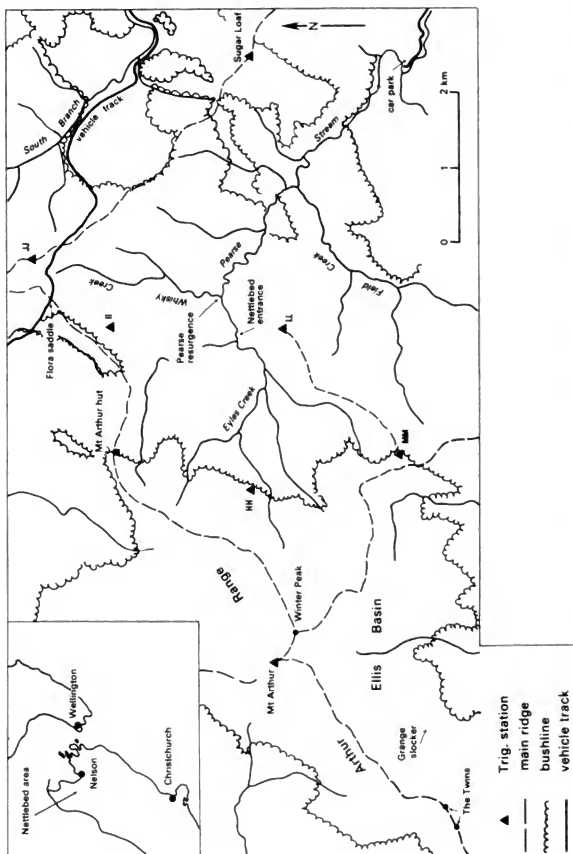
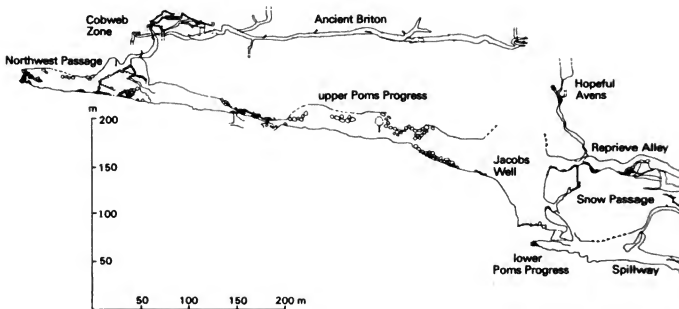


Fig. 1 — The upper Pearse catchment is located on the eastern side of Arthur Range. Inset shows the location of the Nettlebed area with respect to central New Zealand.



Fig. 2 — Oblique aerial view up Pearse Stream to the main ridge of Arthur Range. Photograph (A158a) by S. N. Beatus, reproduced by permission of N.Z. Geological Survey.



West
Fig. 3 — Projection of Nettlebed cave onto a vertical plane aligned magnetic east-west, showing the location of

Nettlebed Expedition allowed exploration upstream including the discovery of Ancient Briton and the Cobweb Zone. By June 1980 surveyed passage length totalled 9.9 km: surveyed height/depth stood at 341 m (Cody, 1980).

The field work upon which this article is based was largely carried out during the 1979-1980 expedition. Grid references given refer to the S13 sheet of the NZMS-1 map series (1:63 360).

Note The term slocker used above comes from the Mendip Hills, southern England, and refers to a more or less vertical hole or shaft into which a stream flows, either continuously or intermittently.

GEOLOGY

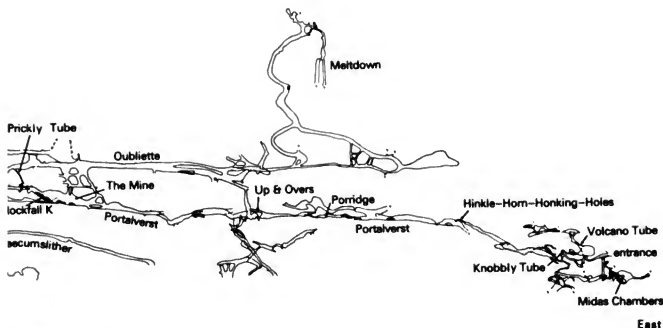
Regional geology

The geology of the upper Pearse catchment, here taken as the area drained by Eyles Creek, Pearse resurgence, and Whisky Creek, has been described by Johnston (1974) and Shannon (1973), but the following summary is condensed from Grindley (1980).

Arthur Range is an uplifted, faulted range of block mountains composed essentially of metamorphosed sedimentary rocks, including the Arthur Marble, Mt Arthur Group (Middle to Upper Ordovician). On the western side of the range these rocks have been overthrust by older (Cambrian) rocks forming the Haupiri Nappes. Along the eastern margin of the range, rocks of Mt Arthur Group are intruded by the Riwaka Igneous Complex (Upper Devonian to Carboniferous) and in places abut Separation Point Granite (Lower Cretaceous).

Several mountain building episodes have deformed these rocks which are now folded into a broad anticline running the length of Arthur Range (see cross-sections in Shannon, 1973; Johnston, 1974; Grindley, 1980). Large faults with both vertical and horizontal displacement trend along the range, branching in the Mt Arthur area to produce several fault-bonded blocks.

The many karst features of the upper Pearse catchment are developed within the Arthur Marble. The limestone precursor of this marble accumulated as a large reef (Grindley, 1980) amid terrigenous sediments, which, in this area, are now represented by the overlying Flora Facies of the Wangapeka Formation.



us parts of the cave.

Geology of the Nettlebed area

Shannon (1973) regarded the marble in the Nettlebed area as belonging to the Twins Member, his uppermost subdivision of Arthur Marble. His description of the unit, based on field work in the Ellis karst field, is largely consistent with my observations around Nettlebed cave.

Lithology. The marble is typically of low metamorphic grade and consists of massive blue-grey marble permeated by an irregular network of recrystallised calcite veinlets, or of alternating laminations, less than 1 cm thick, of white and dark grey marble. These lithologies pass upwards into poorly bedded, less pure marble containing micaceous horizons and layers of quartzite boudin. The upper lithologies in places develop a flaggy appearance — for example, just downstream from the cave entrance.

Petrography. The massive and laminated marble is composed of anhedral, interlocking calcite crystals some of which are twinned. Crystals are typically 0.5 - 1 mm across. Anhedral quartz grains, less than 0.2 mm across, are scattered throughout, and a rare rounded opaque mineral is also present. Strain deformation of cleavage in calcite is evident in the two samples from The Mine area; one of the samples has been brecciated into chips 1-15 mm across and recemented in a very fine grained calcite matrix.

In the upper lithologies the marble is composed of anhedral interlocking calcite crystals about 0.5 mm across. Some crystals show evidence of strain deformation of cleavage. Recrystallised vein calcite is usually in optical continuity with the wall rock. Tiny anhedral quartz grains are scattered throughout, rounded opaque grains form an accessory mineral in most samples, and flakes of white mica, about 0.5 mm long, were found in two samples.

The quartzite boudin are composed of anhedral, interlocking grains of quartz 1 mm or less across. Calcite is present both as a cement, accounting for about 10% of the rock, and as tiny veinlets. The quartz-calcite boundary of the boudin is gradational over 2-3 mm.

Structure. The upper Pearse watershed occupies the southwest portion of a block bounded by major faults, including Thorns Fault to the northwest and Arthur Fault to the south (Fig. 4). This block is cut by numerous small faults (e.g., the fault at the downstream end of the gorge below the cave entrance in Eyles Creek). Jointing is also a prominent feature of the marble, although this aspect was not studied.

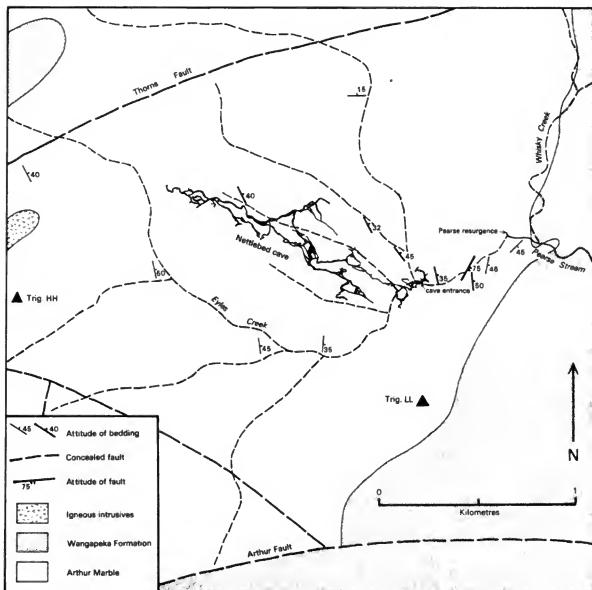


Fig. 4—Geological map of the Nettlebed area after Grindley (1980). New measurements of bedding and a fault are indicated by bold symbols.

Below ground it is not generally possible to distinguish faults from joints, because of the general lack of suitable reference planes in the massive marble. The most notable exceptions are in the entrance series (Fig. 5), where faults are seen to offset bands of quartzite boudin and even the boudin themselves (see below).

Bedding *sensu stricto* is rarely seen; it has been transposed by intense deformation to produce an apparent bedding. However, this transposed bedding seems to be roughly parallel to the plane of true bedding, and elsewhere in this article is simply referred to as "bedding".

The quartzite boudin, well exposed in boulders in the bed of Eyles Creek just below the cave entrance, are formed from the boudinaged limbs of folds or the fold hinges which have become separated from their much attenuated fold limbs (Fig. 6). The enclosing marble displays intricate flow folding. In the Volcano Tube area small faults pass directly through the boudin into the surrounding marble, indicating that both lithologies have been subjected to brittle fracture during a later phase of deformation.

Evidence of fault movement since cave development is preserved by formation in the cave, for instance, broken and recemented columns (Fig. 7) and stalagmites that have developed a second prong after having been displaced.

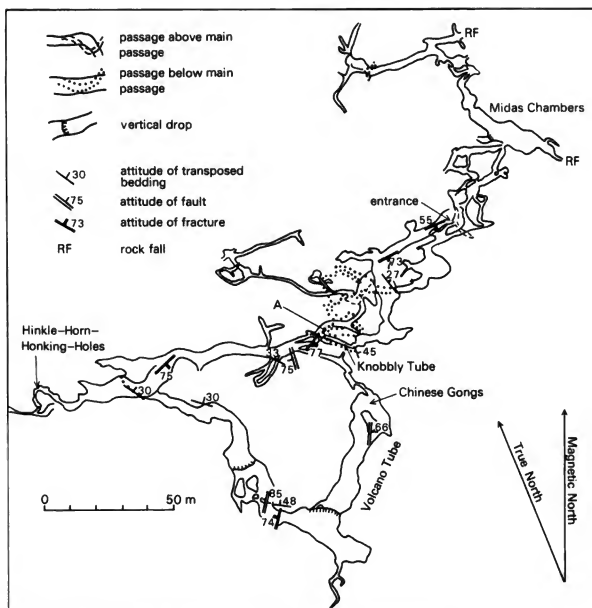


Fig. 5 — Map of the entrance series showing geological measurements.

GEOLOGICAL AND HYDROLOGICAL CONTROLS OF CAVE DEVELOPMENT

The cave is formed in both the massive and laminated marble, and in the overlying flaggy marble. The upper lithologies are particularly noticeable in the entrance series, where quartzite boudin are common (e.g., Knobbly Tube, Volcano Tube), but are also present in several passages in the upper levels (e.g., Tippy Toes).

The cave is essentially a three-dimensional maze of abandoned phreatic tubes that vary in size up to 10 m in diameter. However, much of this phreatic maze is preferentially developed within a plane subparallel to bedding which strikes approximately magnetic east-west and dips 40-50° to the north. This preferential planar development has been controlled by a combination of both bedding and fractures.

Within this plane there are four major levels of passage development: Caecumslither (lowest), Portalverst, Oubliette — Reprieve Alley — upper Poms Progress, and Ancient Briton (highest). The lower two levels are terminated to the west by the Spillway, a rift passage occupied by the main stream. It is postulated that this rift formed along a fault zone that offsets lithologies suitable for cave development. As yet the geology of the Spillway has not been investigated, but the presence of a major fault (Thorns Fault)



Fig. 6 — Boulder in the bed of Eyles Creek exposes quartzite boudin set in marble. The folded nature of the quartzite is evident in some boudin.

parallel to the Spillway and about a kilometre to the west is evidence of nearby faulting along this trend.

Cave development under past phreatic regimes

Most subhorizontal phreatic tubes have formed along fractures, for instance, that section of Portalverst immediately west of the Up and Overs (Fig. 8). However, only in Reprieve Alley, where the slickensided face of a boulder longitudinally bisects two small phreatic tubes (Fig. 9), was it possible to prove that these fractures were definitely faults. Some tubes, instead of having a typical circular cross-section, have an elliptical cross-section elongated in the plane of the fracture (Fig. 10).

Steeply-dipping phreatic passages are typically formed within the plane of bedding, being roughly aligned down dip — for example, the Volcano Tube, which has beds of quartzite boudin exposed along the walls. In most cases these steeply-dipping tubes are not associated with prominent fractures and therefore have slightly flattened oval cross-sections controlled by the plane of bedding.

The Prickly Tube area is a steeply-dipping two-dimensional maze of phreatic tubes (Fig. 11) developed along the bedding plane. Just east of this area more extreme solution of the marble, possibly along a bedding plane fracture, has removed many of the intervening pillars of a similar two-dimensional maze, leaving a large stoped out chamber called The Mine (Fig. 12). This chamber dips at an angle of 40-50° northeast over a vertical height of 40 m.

Scallop markings on the walls of many tubes (Cody, 1980) generally indicate an easterly and upwards current, suggesting that there were once old risings in the vicinity of the Meltdown, and the eastern end of Oubliette passage. Since then the water table has dropped considerably, reaching its present level generally about 25 m below the cave entrance.

Present phreatic regime

When the water table is low enough, normally flooded phreatic tubes become



Fig. 7 — Fractured and recemented column in the passage just west of Hinkle-Horn-Honking-Holes indicates that movement has occurred along the fracture since the column formed. Photograph by R. Newman.

penetrable and offer an excellent opportunity to observe active phreatic passages, for instance, those leading to the Midas Chambers. These fracture-controlled tubes are formed in massive dark grey marble and vary from 1 to 8 m in diameter (A. Cody, pers. comm.). Highly polished pebbles and a lack of mud suggest considerable water turbulence, as do the scalloped walls. The water table in this section of the cave is known to rise dangerously fast (R. Newman, pers. comm.) and although water turbulence may relate to this flooding period turbulence must also be sufficient to maintain mud in suspension when the water is receding. For this reason it is likely that the lower levels do not merely flood with a rising water table but actually have through flow.

During periods of flooding it seems that the water table may rise to the level of the cave entrance, presumably as water backs up in the cave. However, in contrast to the active

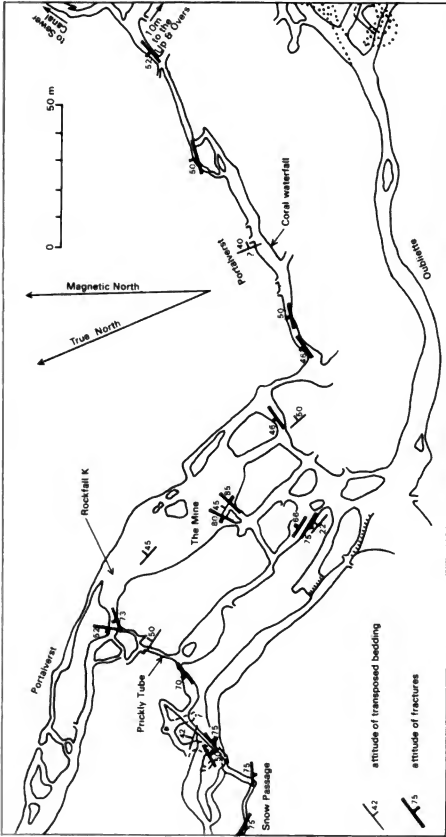


Fig. 8 — Map showing geological measurements in The Mine area and Portalverst west of the Up and Overs.



Fig. 9 — The slickensided face of a boulder in Reprieve Alley bisects two small phreatic tubes. Drawing from photograph.



Fig. 10 — Phreatic tube above Snow Passage has elliptical cross-section aligned along a fracture in the marble. Drink bottle for scale. Photograph by R. Newman.



Fig. 11 — Two-dimensional phreatic maze in the Prickley Tube area. The camera is looking down at about 40°. Photograph by R. Newman.



Fig. 12 — The stoped out area of The Mine. Photograph by R. Newman.

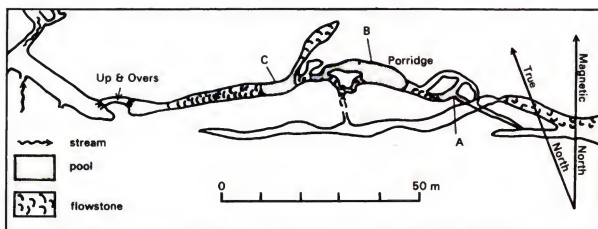


Fig 13 — Map showing various features in Portalverst east of the Up and Overs. "A", "B", and "C" indicate percolation-fed pools of variable depth (see Percolation Water).



Fig. 14 — Dirt lines rim the walls in Porridge passage indicating past water levels. Photograph by R. Newman.

phreatic tubes below, micaceous sand in some higher level passages near the entrance is redistributed (Cody, 1979) by flood waters that merely rise and recede without significant water turbulence.

There is about 0.7 km between where the main stream sumps in the cave and Pearse resurgence. Water flow is probably phreatic over much, if not all, of this distance. From observations around the Pearse resurgence, J. Ash (pers. comm.) has postulated that phreatic drainage is forced to the surface by the presence of insoluble argillaceous rocks (Fig. 4).

Past and present vadose stream regimes

The main stream issues from the base of a major rockfall and flows eastwards in a large

rift passage characterised by several major rockfalls; this instability is attributed to the passage having become too large to support itself. The stream then plunges 53 m into Jacobs Well, and flows in a narrower, northeast-trending passage, characterised by several small waterfalls, before it sumps.

In the past, before the formation of Jacobs Well, the main stream probably continued to flow eastwards through Reprieve Alley, sumping in the vicinity of Snow Passage. This explains the apparent continuity of passage size, shape, and instability between Reprieve Alley and the main stream passage above Jacobs Well.

With a significant drop in the water table, possibly caused by tectonic uplift, the main stream probably began to percolate into the postulated fault zone. This new drainage would have cut down into the fault zone relatively quickly, eroding out the large chamber of Jacobs Well and the high rift passages of lower Poms Progress and the Spillway, and leaving Reprieve Alley dry. Possible the small rift passages in the Snow Passage area were formed after the lowering of the water table but before the stream was completely captured by the new Poms Progress-Spillway drainage.

Several small percolation-fed streams, some of which are tributaries of the main stream and others which never meet the main stream, flow northeastwards across the cave. These streams tend to follow abandoned phreatic passages, and some have cut their own rift into the floor of the tube giving the passage a keyhole cross-section (e.g., Hopeful Avens passage). Elsewhere other streams have become entrenched in grooves that are developed along fractures in the rock (e.g., the passage just beyond the Up and Overs, and the two streams flowing through The Mine).

Short sections of Portalverst and the entrance series are characterised by rift passages. These have probably been cut by small streams that have flowed a short distance along the main subhorizontal phreatic tubes before heading downward again towards the water table. At present there are several streams flowing along short sections of Portalverst in this way.

Percolation water

Percolation water, and the calcite formation deposited from it, are present throughout the cave except for the active phreatic tubes. However, percolation is most significant in those parts of the cave which are relatively close to the surface (i.e., upper areas of the entrance series, eastern end of Portalverst, Oubliette and Meltdown passages, and Snow Passage). These areas are well decorated with speleotherm formation, including crystal pools and massive flowstone. Percolation-fed pools, typically dammed by flowstone, are a feature of Portalverst east of the Up and Overs (Fig. 13). For much of the year a percolation-fed pool accumulates in the small passage leading to Porridge creating a sump (A, Fig. 13), and in order to pass, the pool has to be drained by setting up an artificial syphon. In Porridge Passage itself dirt lines and crystal pool deposits also testify to much higher water levels in the past (Fig. 14). The water level in some of these pools changes intermittently but not always as a simple response to rainfall. For instance, one pool (B, Fig. 13) that remained over a metre deep throughout the summer expedition was completely drained by the following Easter, despite heavy rain in the intervening period. As if in response, the next pool into the cave (C, Fig. 13) was deeper by about half a metre.

Another feature attributable to percolation water is the strange screechy sound of the Chinese Gongs. This is the result of water dripping intermittently into holes eroded into the sandy floor at the bottom of the Volcano Tube. Each hole is lined with calcite, enhancing the eerie echo of the dripping water.

CONCLUSIONS

Nettlebed Cave is developed predominantly in massive marble, near the upward transition to a flaggy, less pure marble, within the Twins Member of Arthur Marble. The plane of transposed bedding, fractures in the marble (probably faults), and the successive lowering of the water table are the main controls of cave development. Individual passages are usually developed along fractures, commonly along the intersection of the

fracture with the plane of bedding. In places a phreatic maze is preferentially developed parallel to transposed bedding, possibly along a bedding plane fracture. The successive lowering of the water table has led to at least four major levels within the cave, and the repeated imposition of a vadose drainage regime onto an older system of abandoned phreatic passages.

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NOTE ADDED IN PRESS

Since this paper was submitted for publication there has been further exploration of Nettlebed Cave. During the 1980-81 NZSS Nettlebed Expedition, a second entrance was discovered. It is in the stream bank on the true left of Eyles Creek, about 200 m downstream of the main entrance, and is joined to the Midas Chambers by a complex system of intermittently active phreatic passages. This provides a possible route for the horizontal flow of flood waters at this level.

More passages were also discovered above Oublette, in an area named Birthday Series, and during the 1981-82 expedition a smoke connection was proved between these passages and the surface.

Exploration beyond Salvation Hall has shown the existence of two massive rockfall chambers, linked by abandoned phreatic tubes which are now richly decorated with cave coral and other speleothems. The chambers vary up to 40 m in width and are floored by boulders and screes sloping at 30-35°.

The total length of surveyed passage now exceeds 16 km, and the depth/height stands at 626 m, making this the deepest cave in the Southern Hemisphere, and the longest in New Zealand. Discussion of the geology and geomorphology of the areas discovered since the 1980/81 expedition must await a future paper.

REFERENCES

- Blundell, W. 1975. Pearse Resurgence revisited. *N.Z. Speleological Bulletin* 5: 425-428.
- Cody, A. 1973. Nettlebed, Mt Arthur. *N.Z. Speleological Bulletin* 5: 185-188.
- 1979. Nettlebed cave: the first breakthrough. *N.Z. Speleological Bulletin* 6: 241-254.
- 1980. Nettlebed Cave (map). *N.Z. Speleological Society*.
- Grindley, G. W. 1980. Sheet S13 Cobb (1st Edition), Geological Map of New Zealand 1:63 360. Map and notes. Department of Scientific and Industrial Research, Wellington.
- James, J., and N. Montgomery. 1971. Ellis karstfield 1970-71. *N.Z. Speleological Bulletin* 4: 602-614.
- Johnston, M. R. 1974. Geology of the Mount Arthur District, North-west Nelson. *N.Z. Journal of Geology and Geophysics* 17: 75-92.
- Montgomery, N.; J. James; V. Watson. 1976. Three mini expeditions around Nelson, New Zealand, Christmas, 1973-4. *N.Z. Speleological Bulletin* 5: 533-556.
- Newman, R. 1973. Mount Arthur 1971-72. *N.Z. Speleological Bulletin* 5: 137-162.
- Pugsley, C. 1979. Caves of the Mt Arthur Region, New Zealand. *Caving International Magazine* 4: 3-10.
- Scarf, F. 1972. Mapping average annual surface water resources of the hydrological regions of Nelson, New Zealand. *Journal of Hydrology, New Zealand* 11: 105-126.
- Shannon, H. 1973. Mt Arthur: geology and cave genesis. *N.Z. Speleological Bulletin* 5: 172-184.
- Watson, V.; F. Kahl; J. Donalds; A. Pavey; L. Kermode; J. James; B. Chapman. 1971. Mt Arthur 1969-70: NZSS summer expedition. *N.Z. Speleological Bulletin* 4: 481-511.

Magnetisation of some New Zealand igneous rocks

T. M. Hunt* and E. G. C. Smith**

Values are given for the magnetisation of thirteen groups of igneous rocks from New Zealand: 2 rhyolites, 1 ignimbrite, 1 trachyte, 2 andesites, 6 basalts and 1 peridotite; and ranging in age from Permian-Jurassic to Quaternary.

Values of intensity of magnetisation (J), intensity of induced and remanent components of magnetisation (J_i , J_r), and of the Koenigsberger ratio (Q_r) vary widely within each group; usually between two and four orders of magnitude. The frequency distributions of these values are skewed towards high values (positive skewness) and fit a log-normal distribution. In 73% of the specimens the remanent component of magnetisation is of greater intensity than the induced component and hence cannot be ignored when determining the intensity and direction of magnetisation for interpreting magnetic anomalies.

The best estimate of J to use in interpreting magnetic anomalies over an igneous body in New Zealand is $e^{\mu + \frac{1}{2}\sigma^2}$, where μ and σ are the mean and standard deviation of $\ln J$ of specimens from the body. Basic igneous rock bodies are not necessarily more strongly magnetised than those of intermediate and acidic composition: for Quaternary rocks from the Central Volcanic Region the best estimate of J for rhyolites is 2.67 A/m, for ignimbrites 2.36 A/m, for andesites 9.9 A/m and for basalts 5.32 A/m.

In some groups the directions of magnetisation of individual specimens are widely scattered, but the vector sum directions of all except one group are close to the present field direction.

INTRODUCTION

Magnetisation is an important physical property of rocks. Observations of variations in intensity of the earth's magnetic field, together with laboratory measurements of intensity and direction of magnetisation in rock specimens, can be used to determine the shape and distribution of rock bodies. In this paper we shall largely be concerned with results of such laboratory measurements and their application to the interpretation of these variations.

For completeness we shall define the properties we are interested in; the notation and units used are given in Appendix 1. The magnetisation of a mineral is a vector whose magnitude is the *intensity* of magnetisation and whose direction is specified by *declination*, or azimuth from geographic north and *inclination*, or dip from the horizontal. All minerals, when brought into a magnetic field, acquire an *induced* magnetisation which is lost when they are removed from the field. Some minerals possess in addition, a *remanent* magnetisation which is present even in the absence of an external field. We shall denote by J_i and J_r the induced and remanent magnetisations of the mineral, and the total magnetisation J is the vector sum of these:

$$J = J_i + J_r \quad (1)$$

Minerals differ in their capacity to acquire an induced magnetisation from the application of an external magnetic field. This capacity is specified by the *magnetic susceptibility* (χ); it is a dimensionless quantity and is defined as the ratio of intensity of induced magnetisation (J_i) to intensity of applied field (H). The direction of the induced magnetisation is taken as that of the applied field; hence, for a mineral situated in a local field (H_0):

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$$\mathbf{J}_i = \chi \cdot \mathbf{H}_0 \quad (2)$$

and so:

$$\mathbf{J} = \chi \cdot \mathbf{H}_0 + \mathbf{J}_r \quad (3)$$

Rocks are aggregates of different minerals. The magnetisation of a rock is usually determined by the strongly magnetic (ferromagnetic) minerals in it and has the same magnetic properties as the constituent minerals.

To determine the shape and distribution of a rock body the observed variations in magnetic field intensity are generally compared with those calculated for various theoretical bodies. However, to calculate the magnetic effects of a rock body at an external point, it is necessary to assume that the body is homogeneously magnetised and to adopt a representative value for \mathbf{J} . This value for \mathbf{J} is commonly obtained using laboratory measurements of χ and \mathbf{J}_r from a set of specimens taken from the body and field measurements of \mathbf{H}_0 . The question of how to obtain an appropriate representative value for \mathbf{J} from the measurements is not trivial, and we will consider this problem in detail.

DATA USED

The data used in this study were taken from the files of Geophysics Division, New Zealand Dept. of Scientific and Industrial Research (Whiteford and Lumb, 1975), which list the location, rock type, susceptibility, and intensity, declination and inclination of remanent magnetisation for specimens of rocks collected from all parts of New Zealand. To simplify calculation of the induced components of magnetisation, it has been assumed that the earth's magnetic field has an intensity $H_0 = 58\,000$ nT, declination $D = 20^\circ$ E, and inclination $I = -67^\circ$ (upwards) throughout New Zealand. At present (1980), the intensity of the regional field at the locations discussed in this paper varies between about 55 000 and 61 000 nT, the declination between 18.5° and 23° E, and the inclination between -62.5° and -71° . The errors introduced by the approximation are about the same as those introduced by local variations in the field.

The names used to describe the rocks are not the same as those that would be used by a petrologist. The name 'basalt' is used here for all fine- and medium-grained, mafic, igneous rocks and includes dolerites, basanites, mugearites, limburgites, and olivine-basalts; 'peridotite' includes pyroxenites, and partly serpentinised peridotites; 'trachyte' includes phonolites and kaihikites.

DISTRIBUTION OF MAGNETIC INTENSITY VALUES: SAMPLING THEORY

Irving *et al.* (1966) showed that values of intensity of remanent and induced magnetisation for samples of Torridonian sandstones from Great Britain have a log-normal distribution, and Cox (1971) demonstrated that this is also true for andesites and ignimbrites from the North Island of New Zealand. We later show that this is a general property of groups of New Zealand igneous rocks; that $\Gamma = \ln J$ has a probability density function given by

$$f(\Gamma) = (2\pi\sigma^2)^{-1/2} e^{-\frac{1}{2\sigma^2}(\Gamma - \mu)^2} \quad (4)$$

where μ and σ are the mean value and standard deviation of $\ln J$. It is to be understood in taking the logarithm of J that J is measured in A/m. An example of the distribution is given in Figure 1: Figure 1a shows a histogram of magnetic intensity values together with the best fitting curve $f(\Gamma)$; Figure 1b shows the corresponding histogram of log intensity. Specific details for each site will be given later together with an analysis of the differences between the sites. It suffices for the moment to note that only one of thirteen samples had a distribution significantly different (at the 5% level) from a log-normal distribution. We shall now consider the consequences for anomaly modelling of adopting a log-normal model for the distribution of intensity values.

Assuming that the intensity of magnetisation (J) has a log-normal distribution, we wish to determine the statistic which provides the 'best' estimate for J from measurements on a set of specimens (hereafter called a sample) from a rock body. This is a difficult problem; there may be a different solution for each body. Furthermore, it is necessary to assume that the sample fairly represents the body. We can make progress in a general situation by adopting conventional criteria for deciding what are good and bad estimates of J . Two such criteria are: (1) the estimate should be unbiased, that is, the average of a large number of such estimates should be close to the average value of J for each body; (2) the estimate should have as small a standard deviation as possible.

A conventional method for determining a 'best' statistic or statistics from a set of observations with a known distribution is the method of maximum likelihood, which we will now apply to the distribution of magnetic intensities.

If $\Gamma = \ln J$ has a probability density function given by Equation (4), then it follows that the probability density function for J is given by:

$$f(J) = (2\pi \sigma^2 J^2)^{-1/2} e^{-(\ln J - \mu)^2 / 2\sigma^2} \quad (5)$$

which is completely specified once μ and σ are known. If \bar{J} and s are the mean and standard deviation of J , then:

$$\bar{J} = e^{\mu + 1/2 \sigma^2} \quad (6a)$$

$$s = e^{\mu + 1/2 \sigma^2} (e^{\sigma^2} - 1)^{1/2} \quad (6b)$$

For a point sufficiently remote from a rock body to allow the assumption that the variation of distances of different parts of the body from the point can be neglected, \bar{J} is the correct representative value for the intensity of magnetisation. We estimate \bar{J} by forming the likelihood function

$$\begin{aligned} \lambda(\mu, \sigma) &= \prod_{k=1}^n f(J_k) \\ &= \Pi (2\pi \sigma^2 J_k^2)^{-1/2} e^{-(\ln J_k - \mu)^2 / 2\sigma^2} \end{aligned} \quad (7)$$

(where Π denotes product and $\{J_k : k = 1, 2, \dots, n\}$ is the set of values of magnetisation of the sample) and by noting that this has a maximum when $\Lambda = \ln \lambda(\mu, \sigma)$ has a maximum, and that this occurs when $\partial \Lambda / \partial \mu = 0$ and $\partial \Lambda / \partial \sigma = 0$. These equations give the following estimates for μ and σ :

$$\mu = \frac{1}{n} \sum_{k=1}^n \ln J_k \quad (8a)$$

$$\sigma = \left\{ \sum_{k=1}^n (\ln J_k - \mu)^2 / n \right\}^{1/2} \quad (8b)$$

In fact, we substitute:

$$\sigma = \left\{ \sum_{k=1}^n (\ln J_k - \mu)^2 / (n - 1) \right\}^{1/2} \quad (8c)$$

because it is an unbiased estimate of the standard deviation. The effect of this change is negligible for samples with n (number of specimens) greater than about 20. Estimates for \bar{J} and s are obtained by substituting into Equations (6) the values for μ and σ from Equations (8).

We shall now briefly give some of the properties of this estimate of \bar{J} and compare it with $\sum_{k=1}^n J_k / n$, which is always an unbiased estimate of \bar{J} , whatever the distribution of J

might be. Further details are given in Appendix 2; some are given by Aitchison and Brown (1957).

In fact, $e^{\mu + \frac{1}{2}\sigma^2}$ is a biased estimate.

The average value of $e^{\mu + \frac{1}{2}\sigma^2}$ is given by:

$$e^{(\mu + \frac{1}{2n}\sigma^2)} \left[\frac{n-1}{n-1-\sigma^2} \right]^{\frac{n-1}{2}} \quad (9)$$

which converges to $e^{\mu + \frac{1}{2}\sigma^2}$ as $n \rightarrow \infty$.

The standard deviation of $e^{\mu + \frac{1}{2}\sigma^2}$ is given by

$$e^{\mu + \frac{1}{2n}\sigma^2} \left[e^{\frac{\sigma^2}{n}} \left(\frac{n-1}{n-1-2\sigma^2} \right)^{\frac{n-1}{2}} - \left(\frac{n-1}{n-1-\sigma^2} \right)^{n-1} \right]^{\frac{1}{2}} \quad (10)$$

By way of comparison, the standard deviation of $\sum_{k=1}^n J_k/n$ is given by

$$(1/\sqrt{n})s = (1/\sqrt{n})e^{\mu + \frac{1}{2}\sigma^2} (e^{\sigma^2} - 1)^{\frac{1}{2}} \quad (11)$$

Both of these quantities converge to zero as $n \rightarrow \infty$ but the former converges much more

rapidly. To show the properties of $e^{\mu + \frac{1}{2}\sigma^2}$ as an estimate compared to $\sum_{i=1}^n J_i/n$, values for

$$\left\{ e^{\mu + \frac{1}{2n}\sigma^2} \left[\frac{n-1}{n-1-\sigma^2} \right]^{\frac{n-1}{2}} \right\} / \left\{ e^{\mu + \frac{1}{2}\sigma^2} \right\}$$

which measures the bias, and the two standard deviations, are listed in Table 1 for values of μ , σ , and n for the groups considered in this paper. It can be seen that for samples containing at least 30 specimens the estimate $e^{\mu + \frac{1}{2}\sigma^2}$ is superior, but not overwhelmingly so. For Canterbury andesites, and Chatham Islands (B) basalts, the $e^{\mu + \frac{1}{2}\sigma^2}$ estimate is distinctly superior. Aitchison and Brown (1957) suggest an alternative estimate:

$$e^{\mu} \psi(\sigma^2/2)$$

where

$$\psi(x) = 1 + \sum_{k=1}^{\infty} \frac{(n-1)^{2k}}{n^k(n+1)(n+3)\dots(n+2k-3)} \frac{X^k}{k!} \quad (12)$$

This estimate has the advantage of being unbiased, but it is difficult to calculate, is insignificantly different from $e^{\mu + \frac{1}{2}\sigma^2}$ for values of n greater than about 20 and σ less than 1.5 (as is the case for the samples considered here), and no expression for the standard deviation can be determined for it.

DISTRIBUTION OF MAGNETIC INTENSITY VALUES: DATA AND RESULTS

Sampling

The data from the files were sorted according to rock type, and where possible, were grouped according to location and age.

The samples are generally not as representative of the locations as we would like, but no additional data were added to the file data to improve the representation because a substantial programme of sampling would be required to achieve a worthwhile improvement. In some cases, most of the specimens are from a small number of localities: 19 of the 27 andesites from the Central Volcanic Region are from a small area near the

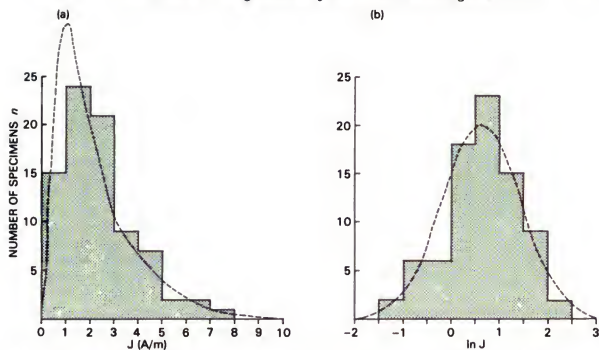


Fig. 1 — Histograms showing the frequency distribution of (a) intensity of magnetisation (J), and (b) $\ln J$, for basalt from Otago Peninsula. The broken line in (a) is the theoretical log-normal distribution and in (b) is the theoretical normal distribution, for a population with the same mean and standard deviation as the sample. A value for J of 11.9 A/m is not plotted.

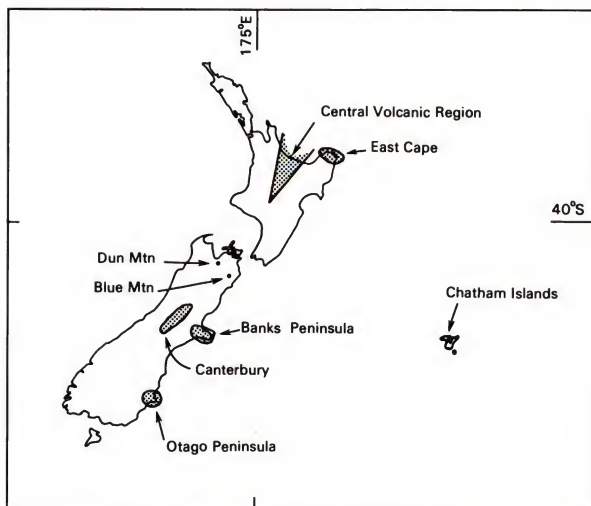


Fig. 2 — Location of the groups of New Zealand igneous rocks studied.

TABLE 1: Values of intensity of magnetisation and their distribution statistics for groups of New Zealand igneous rocks. The locations of the rocks are shown in Fig. 2. Note that for all J but one group K is less than K_5 . The reader is also invited to compare the two estimates of magnetisation: e^{+h_2} and mean J .

| ROCK TYPE | LOCATION | AGE | n | Mean Int. J (e) | Std. Dev. Int. J (e) | $e^{+h_2 \cdot 10^{-2}}$ | Std. Dev. $e^{+h_2 \cdot 10^{-2}}$ | Bias | K (%) | K ₅ (%) | Mean J | Std. Dev. Mean J |
|------------|----------------------------|------------|----|-----------------------------|----------------------------------|--------------------------|---------------------------------------|------|----------|-----------------------|----------|-----------------------|
| RHYOLITE | Central Volcanic Region | Quaternary | 29 | 0.319 | 1.15 | 2.67 | 0.80 | 1.04 | 9 | 24.6 | 2.47 | 0.82 |
| | Canterbury | Cretaceous | 22 | -0.808 | 1.55 | 1.48 | 0.97 | 1.14 | 15 | 28.0 | 0.714 | 1.00 |
| IGNIMBRITE | Central Volcanic Region | Quaternary | 21 | 0.484 | 0.863 | 2.36 | 0.55 | 1.03 | 19 | 28.7 | 2.10 | 0.54 |
| | Central Volcanic Region | Quaternary | 27 | 2.01 | 0.752 | 9.90 | 1.67 | 1.01 | 18 | 25.5 | 9.65 | 1.66 |
| ANDESITE | Canterbury | Cretaceous | 36 | 0.624 | 1.39 | 4.90 | 1.80 | 1.06 | 16 | 22.7 | 1.47 | 2.00 |
| | Otago Peninsula | Miocene | 13 | 0.0206 | 0.790 | 1.39 | 0.38 | 1.03 | 14 | 36.1 | 1.14 | 0.16 |
| TRACHYTE | Central Volcanic Region | Quaternary | 13 | 1.63 | 0.285 | 5.32 | 0.43 | 1.00 | 8 | 36.1 | 5.10 | 0.43 |
| | Banks Peninsula | Miocene | 10 | 0.425 | 0.643 | 1.88 | 0.45 | 1.03 | 23 | 40.9 | 1.81 | 0.41 |
| BASALT | Chatham Islands | Pliocene | 23 | 1.77 | 1.52 | 18.6 | 11.2 | 1.12 | 33 | 27.5 | 9.38 | 11.7 |
| | Chatham Islands (B) | Eocene | 84 | 1.96 | 0.935 | 11.0 | 1.37 | 1.01 | 11 | 14.8 | 10.1 | 1.42 |
| | Otago Peninsula | Miocene | 82 | 0.608 | 0.814 | 2.56 | 0.2 | 1.01 | 6 | 15.0 | 2.43 | 0.27 |
| | East Cape | Cretaceous | 18 | 1.25 | 0.579 | 4.13 | 0.62 | 1.01 | 25 | 30.9 | 1.92 | 0.61 |
| PERIDOTITE | Dun Mountain | Permian- | 26 | 1.21 | 1.50 | 10.3 | 5.5 | 1.10 | 17 | 25.9 | 8.78 | 5.9 |
| | Blue Mountain | Jurassic | | | | | | | | | | |

n = number of specimens

J = Intensity of magnetisation (A/m)

e^{+h_2} = Kolmogorov-Smirnov statistic (frequency, %)

K₅ = Kolmogorov-Smirnov statistic (%) at 5% confidence level

for a two-sided test.

southern portal of the Rangipo Headrace Tunnel; 22 of the 26 peridotites are from Dun Mountain, near Nelson. As a minimum standard only samples with 10 or more specimens have been considered; this yields the 13 groups listed in Table 1. The locations of the groups are shown in Figure 2.

Care must be taken when collecting specimens for the measurement of properties to use in interpreting magnetic anomalies associated with a geological body. Firstly, the geological boundaries of the body may not coincide with the magnetic boundaries. One example of this is the Rotorua Igneous Complex, where bands of strongly magnetic gabbro occur within weakly magnetic mafic and intermediate intrusives (Wellman, 1973); another is at Glenorchy, where weakly magnetic chlorite subzone 3 schists, near scheelite lodes, have become strongly magnetised (Risk *et al.*, 1977). Secondly, parts of the body may have distinctly different, but uniform, magnetisation. An example is the sequence of lava flows on Otago Peninsula; most of the flows are normally magnetised, but some are reversely magnetised (Coombs and Hatherton, 1959), so that the intensity of the vector sum of the whole sequence is less than that for each flow. Sampling to allow detailed interpretation of magnetic anomalies over such a body can be complex and, in some cases, impossible in practice.

For the above reasons, the values of magnetisation given here should be treated with caution when interpreting magnetic anomalies; nevertheless, we believe that they give a reliable guide to the distribution and magnitudes that will be found by detailed sampling.

Log-normal distribution

A histogram (Fig. 1a) of the frequency distribution of intensity of magnetisation (J) for a group with a large number of specimens (82), the basalts from Otago Peninsula, is noticeably skewed towards high values of J (i.e., positively skewed). However, the distribution of $\ln J$ (Fig. 1b) approximates a normal distribution, suggesting that intensity of magnetisation in these rocks follows a log-normal distribution.

We do not have a sufficient number of specimens in most other groups to establish, using histograms, that J always has a log-normal distribution. To test this premise the cumulative frequency functions of the logarithm of intensity of magnetisation for each group were plotted on normal probability paper, together with best fitting straight lines (Figs. 3 and 4). The maximum departure, in frequency, of the cumulative frequency function from the best fitting straight line, is the Kolmogorov-Smirnov statistic (K), which is good measure of departure from normality of each set of log-intensities. Maximum departures (K), together with appropriate 5% confidence level values (K_s), are given for each group in Table 1. For all except one group (Pliocene basalts, Chatham Islands), K is less than K_s , indicating that a log-normal distribution is an excellent model for the distribution of magnetic intensity values.

Examination of the values of J for the group which appears not to have a log-normal distribution shows that the line of best fit is greatly affected by two specimens with very low values of intensity of magnetisation (Fig. 4); the values are nearly two orders of magnitude less than that for others in the group. It is possible that these two specimens are anomalous; the specimens may have been altered during or after being collected, or they may have been wrongly assigned to the group. If these specimens are excluded from the group and a line best fit drawn through the values for the remaining 21 specimens in the above manner, the value of K is 17% and that of K_s is 28.7% indicating a good fit to a log-normal distribution.

Neglecting the two possibly anomalous specimens, the data indicate that in all groups the magnetic intensity values have a log-normal distribution. The mean and standard deviation of the logarithms of the intensities (μ and σ respectively) are therefore the appropriate statistics to consider when determining if there is a difference between two samples, and $e^{\mu + \frac{1}{2}\sigma^2}$ is the best representative value of J to use when calculating the magnetic effect of rock bodies.

Variation of intensity

The histograms (Fig. 1) and frequency plots (Figs. 3 and 4) also show that, for most

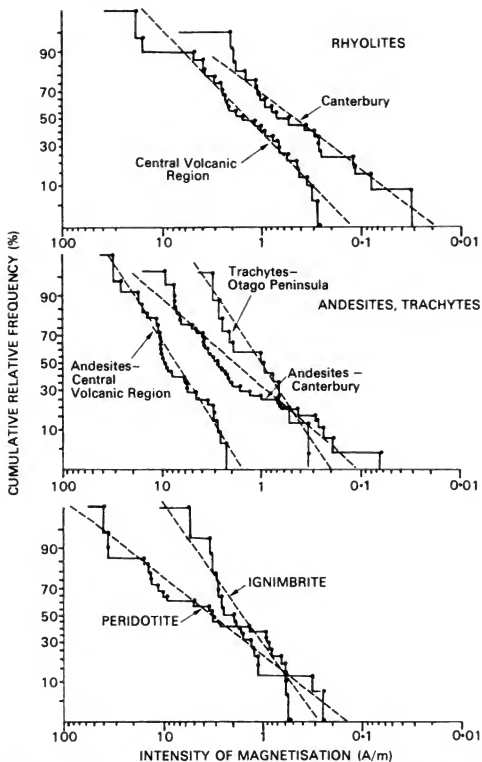


Fig. 3 — Plots of cumulative relative frequency against intensity of magnetisation (J) for rhyolites, andesites, trachytes, ignimbrites and peridotites. The broken lines represent plots of the theoretical log-normal distributions for populations with the same means and standard deviations.

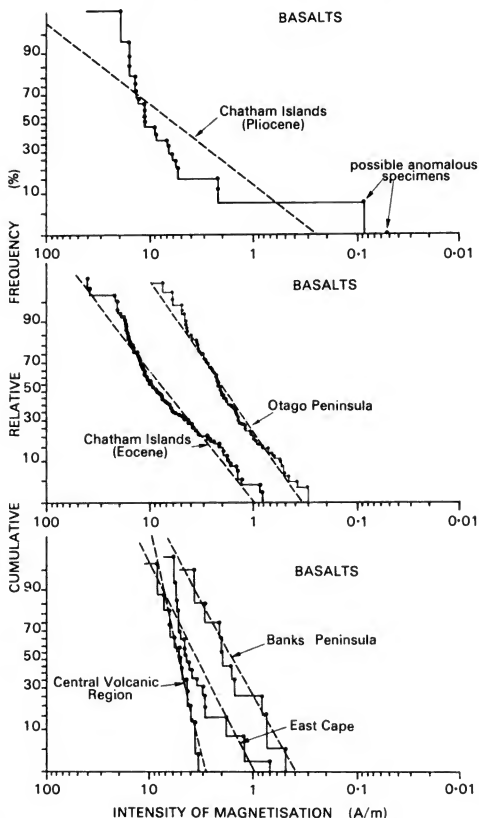


Fig. 4 — Plots of cumulative relative frequency against intensity of magnetisation (J) for basalts. The broken lines represent plots of the theoretical log-normal distributions for populations with the same means and standard deviations. Note the close fit between the plots and the theoretical log-normal distributions for basalts from the Central Volcanic Region and from Otago Peninsula.

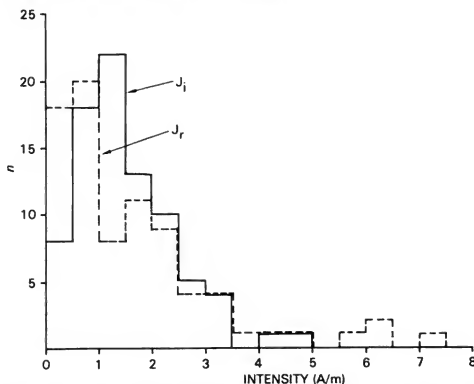


Fig. 5—Histograms showing the frequency distribution for intensity of remanent (J_r) and induced magnetisation (J_i) of specimens of basalt from Otago Peninsula. A value of $J_r = 11.5$ A/m is not plotted.

groups, the intensity of magnetisation varies over two or more orders of magnitude. In this respect magnetisation is like some other physical rock properties such as electrical resistivity and permeability, but unlike density, thermal conductivity and seismic velocity which vary over one order of magnitude.

The data given in Table 1 show that basic igneous rocks are not necessarily more strongly magnetised than rocks of acidic or intermediate composition; for Quarternary igneous rocks from the Central Volcanic Region, the value of $e^{\mu + 1/2\sigma^2}$ is $2.67 (\pm 0.80)$ for rhyolites, $2.36 (\pm 0.55)$ for ignimbrites, $5.32 (\pm 0.43)$ for basalts, and $9.90 (\pm 1.67)$ for andesites. The value for andesites, rocks of intermediate composition, is clearly greater than that for basic rocks (basalts). The data also show that young rocks are not necessarily more strongly magnetised than old ones: the value of $e^{\mu + 1/2\sigma^2}$ for Eocene basalts (35–53 m.y. old) from the Chatham Islands is $11.0 (\pm 1.37)$ but for Miocene basalts (10–12 m.y. old) from Banks Peninsula it is $1.88 (\pm 0.45)$.

The data confirm that the age and type of a rock are not important factors in determining its intensity of magnetisation; the important factors are the composition of the magnetic minerals, their distribution in the rock, how they were magnetised, and the metamorphic history of the rock (Nagata, 1961).

Induced and remanent magnetisation

Values of J_i and J_r vary over at least two orders of magnitude in all groups. Histograms of intensity values of induced (J_i) and of remanent (J_r) magnetisation of basalts from Otago Peninsula (Fig. 5) are positively skewed suggesting that these components also have log-normal distributions. Cumulative frequency plots (Fig. 6) for the natural logarithm of induced and remanent intensities for three other groups all fit the log-normal distribution model very well, and we postulate that this distribution describes the distribution of these components for all groups. Statistics for the distribution of J_i and J_r for each group are given in Table 2.

Origin of the log-normal distribution

The above data show that the log-normal distribution holds for a wide range of igneous

TABLE 2: Values of induced and remanent magnetisation and Koenigsberger Ratio for New Zealand igneous rocks. The locations of the rocks are shown in Fig. 2; the ages of the rocks and the number of specimens are given in Table 1.

| ROCK TYPE | LOCATION | INDUCED MAGNETISATION | | | REMANENT MAGNETISATION | | | KOENIGSBERGER RATIO | | |
|------------|-------------------------|-------------------------|-----------------------------|------------|-------------------------|-----------------------------|------------|-------------------------|-----------------------------|------------|
| | | Mean in J_i (n) | Std Dev. in J_i (o) | e^{+J_i} | Mean in J_r (n) | Std Dev. in J_r (o) | e^{+J_r} | Mean in J_r (n) | Std Dev. in J_r (o) | e^{+J_r} |
| RHYOLITE | Central Volcanic Region | -1.55 | 0.900 | 0.320 | 0.0420 | 1.27 | 2.33 | 1.6 | 1.4 | 13 |
| | Canterbury | -1.99 | 1.26 | 0.302 | -1.46 | 1.97 | 1.62 | 0.53 | 1.5 | 5.1 |
| IGNIMBRITE | Central Volcanic Region | -1.01 | 0.432 | 0.400 | 0.176 | 1.08 | 2.14 | 1.2 | 0.76 | 4.5 |
| ANDESITE | Central Volcanic Region | -0.907 | 0.666 | 0.505 | 1.89 | 0.908 | 9.95 | 2.8 | 1.5 | 49 |
| | Canterbury | -2.01 | 1.27 | 0.299 | 0.404 | 1.66 | 5.97 | 2.4 | 1.8 | 55 |
| TRACHYTE | Otago Peninsula | -0.275 | 0.715 | 0.981 | -1.30 | 1.10 | 0.499 | -1.0 | 0.77 | 0.48 |
| BASALT | Central Volcanic Region | -0.315 | 1.17 | 1.46 | 1.25 | 0.542 | 4.02 | 1.6 | 1.6 | 18 |
| | Banks Peninsula | -0.107 | 0.565 | 1.05 | 0.0966 | 0.741 | 1.45 | 0.21 | 0.62 | 1.5 |
| | Chatham Islands (A) | -0.173 | 1.16 | 1.65 | 1.60 | 1.69 | 20.5 | 1.8 | 0.83 | 8.3 |
| | (B) | -0.140 | 0.998 | 1.43 | 1.78 | 0.989 | 9.71 | 1.9 | 1.1 | 12 |
| | Otago Peninsula | 0.168 | 0.831 | 1.72 | 0.122 | 0.991 | 1.85 | -0.047 | 1.2 | 1.9 |
| | East Cape | 0.726 | 0.643 | 2.54 | 0.282 | 0.730 | 1.74 | -0.44 | 0.78 | 0.87 |
| PERIDOTITE | Dun Mtn., Blue Mtn. | -0.562 | 0.787 | 0.777 | 1.03 | 1.69 | 11.6 | 1.6 | 1.4 | 13 |

 J_i = Intensity of induced magnetisation (A/m) J_r = Intensity of remanent magnetisation (A/m) $Q_n = J_r/J_i$ ρ = Correlation coefficient for $\ln J_r$, $\ln J_i$.

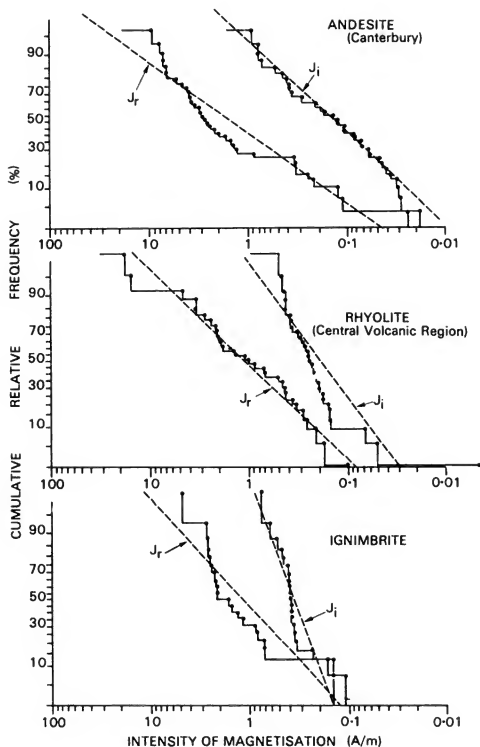


Fig. 6 — Plots of cumulative relative frequency against intensity of remanent (J_r), and of induced magnetisation (J_i), for groups 1, 3 and 5 (Table 3). The broken lines represent plots for the theoretical log-normal distributions for populations with the same means and standard deviations.

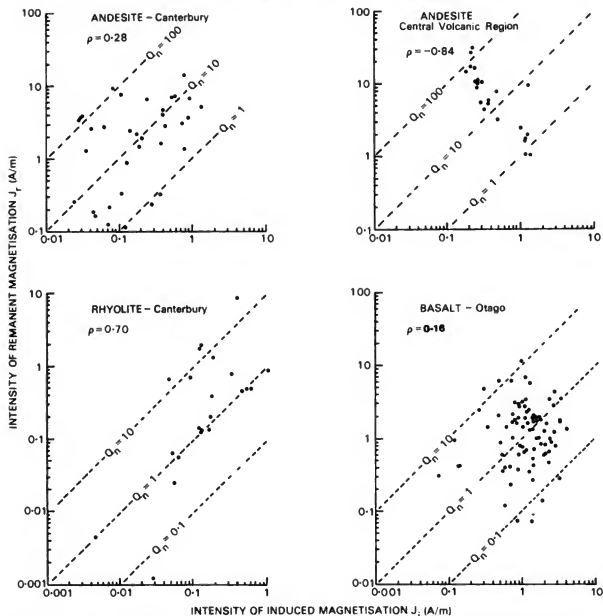


Fig. 7 — Plots of intensity of remanent magnetisation (J_r) against intensity of induced magnetisation (J_i) for four of the groups studied. Values for each specimen are plotted as solid dots. ρ is the correlation coefficient for $\ln J_r$ and $\ln J_i$. The broken lines represent lines of equal Koenigsberger ratio (Q_n). Note the wide scatter of the dots.

rock types and for rocks ranging in age from Permian-Jurassic to Quaternary; it also holds for both the induced and remanent components of magnetisation. This suggests that the distribution is likely to be related to a basic property of the rocks and is unlikely to be greatly modified by differences in the composition of the rocks, by their subsequent history, or by variations in the earth's magnetic field during or subsequent to their formation.

According to Stott (*in* Stacey, 1963: 94) the volumes of magnetic grains in igneous rocks commonly have a log-normal distribution, and McElhinny (1973) shows that for magnetite grains of up to 20×10^{-6} m diameter, with pseudo-single magnetic domains, the intensity of thermal remanent magnetisation is inversely proportional to grain diameter. This suggests that grain size may be the dominant factor causing the log-normal distribution of J_r , J_i and J_r/J_i .

Aitchison and Brown (1957) make a few comments about the genesis of the log-normal distribution in general; they consider that it arises from the modification of a uniform distribution by a large number of random factors. Thus, when the logarithm of the variable is taken, the transformed variable is the sum of a large number of random effects, and such sums tend to have a normal distribution.

The origin of the distribution, as it occurs in rock magnetism, is unknown and warrants further investigation; however, this is beyond the scope of this paper and the competence of the writers.

Koenigsberger ratio

The Koenigsberger ratio (Q_n), defined to be J_r/J_i , is an often-quoted, but seldom-used parameter determined in rock magnetisation studies.

Of the 404 specimens in this study, 295 (73%) have $Q_n \geq 1$; and of the 75 specimens with $J \geq 10$ A/m, none had $Q_n < 1$. Hence, remanent magnetisation is a very important component of magnetisation and cannot be ignored when determining the magnetisation of a rock for use in interpreting magnetic anomalies.

Since $\ln Q_n = \ln J_r - \ln J_i$, Q_n will have a log-normal distribution if J_r and J_i have log-normal distributions, with the mean value of $\ln Q_n$ equal to the difference in means of $\ln J_r$ and $\ln J_i$. The mean and standard deviation of the logarithms of Q_n are therefore the appropriate statistics to consider when determining if there is a difference between the Koenigsberger ratios of two or more groups, and $e^{\mu + \frac{1}{2}\sigma^2}$ is the best representative value of Q_n . These statistics, for each group, are given in Table 2.

If σ_q is the standard deviation of $\ln Q_n$, and σ_r and σ_i are the standard deviations of $\ln J_r$ and $\ln J_i$, then σ_q is given by

$$\sigma_q^2 = \sigma_r^2 + \sigma_i^2 - 2\sigma_r\sigma_i\rho$$

where ρ is the correlation coefficient for $\ln J_r$ and $\ln J_i$. If the standard deviations have been calculated using $n - 1$, rather than n , in the division of the sum of squares (to make the estimates unbiased), then ρ should be calculated by

$$\rho = \frac{n-1}{n-2} \left[\frac{\sigma_r^2 + \sigma_i^2 - \sigma_q^2}{2\sigma_r\sigma_i} \right]$$

Values of the correlation coefficient (ρ) for each group, are given in Table 2; the values are generally positive, a few being close to unity, but there is a wide variation showing that there is no consistent relation between J_r and J_i . Plots of J_r and J_i , an example of which is given in Figure 7, show that the variation of Q_n values is caused by variation of both components.

Variation of Q_n with age

According to Nagata (1961), values of Q_n decrease as the ages of rocks increase due to a decrease in intensity of remanent magnetisation resulting from relaxation effects.

The data from Table 2 show that for some rocks (andesites, rhyolites, and some basalts) this appears to be true, but the standard deviations of $\ln Q_n$ (σ_q ; Table 2) are such that the differences in Q_n with age are not significant.

Q_n as an indicator of palaeomagnetic stability

Stacey and Banerjee (1974) state that for rocks with thermoremanent magnetisation, values of Q_n greater than 0.5 indicate that the remanent magnetisation resides mainly in pseudo-single domains of high coercivity, and the rocks have high palaeomagnetic stability. The values of $e^{\mu + \frac{1}{2}\sigma^2}$ (for Koenigsberger ratio) exceed 0.5 for all but one group (trachytes) sampled here (Table 2), so most of the rocks should be suitable for palaeomagnetic investigations; detailed studies of the andesites and rhyolites from Canterbury (Oliver *et al.*, 1979) and of the basalts from Banks Peninsula (Evans, 1970), and from the Chatham Islands (Grindley *et al.*, 1977) have confirmed this. However, data given by Hunt (1974) and Hunt and Mumme (1977) show that many peridotites from Dun Mountain with Q_n values greater than 0.5 are not palaeomagnetically stable. While this test of stability may be true for rocks with thermoremanent magnetisation, this is not necessarily true for rocks with chemical remanent magnetisation, such as peridotites.

BASALTS

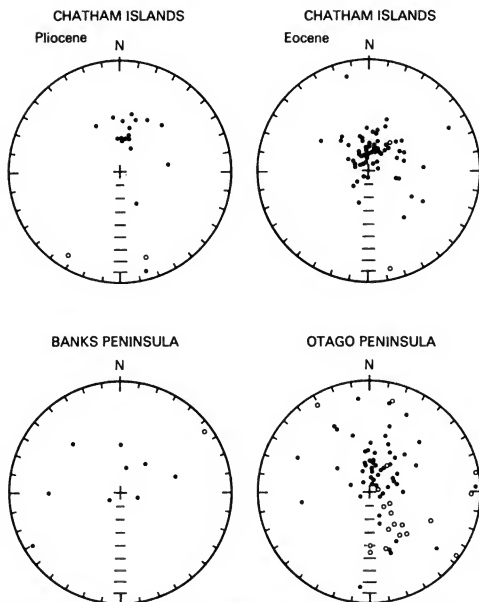


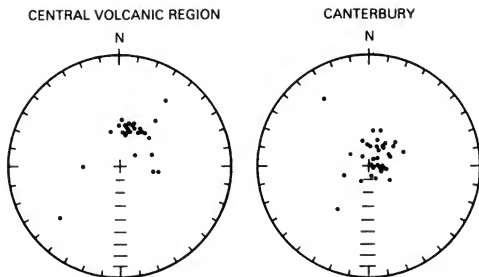
Fig. 8 — Stereograms showing directions of magnetisation in four groups of basalt. An upper hemisphere projection is used. Solid dots indicate an upward (normal) direction of magnetisation; open dots indicate a downward (reverse) direction.

DIRECTION OF MAGNETISATION

Since values of Q_n for most groups of New Zealand rocks studied here are greater than 1, it cannot be assumed *a priori* that the direction of magnetisation in these rocks is close to that of the earth's present magnetic field. The directions of magnetisation of specimens in some groups are widely scattered (Figs. 8 and 9). For interpreting magnetic anomalies, it is the direction of the vector sum of the magnetisation that is important; vector sums for the groups of New Zealand rocks are given in Table 3 (Vector 1). Despite the wide scatter in directions of magnetisation in some groups, the direction of the vector sum for each group, with the exception of that for rhyolites from the Central Volcanic Region (Group 1) is within 20° of the direction of the present field (Fig. 10).

In most palaeomagnetic studies a mean value for directions of magnetisation is calculated assuming a unit vector (i.e. $J = 1$) for each specimen. Mean values for each group calculated this way are given in Table 3 (Vector 2) and Figure 10. The angular differences between this direction, the direction of the vector sum, and the present field

ANDESITES



RHYOLITES

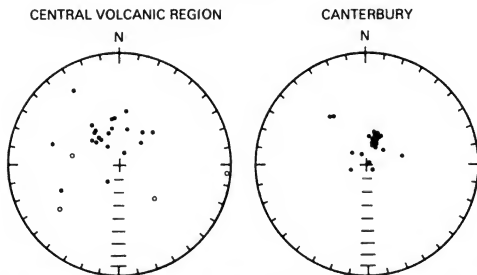


Fig. 9 — Stereograms showing directions of magnetisation in two groups of andesites and two groups of rhyolites. An upper hemisphere projection is used. Solid dots indicate an upward (normal) direction of magnetisation, open dots indicate a downward (reverse) direction.

were calculated using a Wulff stereographic net and are given in Table 3 (θ , λ , ω). For most groups the direction assuming unit vectors is similar to the direction of the vector sum, and similar to the present field.

It should be noted, however, that while the difference between the direction of the present field and that of the vector sum of unit vectors (ω ; Table 3) for most groups is small (generally $< 20^\circ$), and can be neglected when interpreting magnetic anomalies, the difference may be significant when considering palaeomagnetic pole positions.

CONCLUSIONS

Measurements of the magnetisation in specimens taken from 13 groups of igneous rocks in New Zealand show that:

- (1) Values of intensity of magnetisation (J), intensity of induced (J_i) and remanent magnetisation (J_r), and Koenigsberger ratio (Q_n) vary between two and four orders of magnitude, and have a log-normal distribution.
- (2) Directions of magnetisation may vary widely, but the vector sum direction, and the

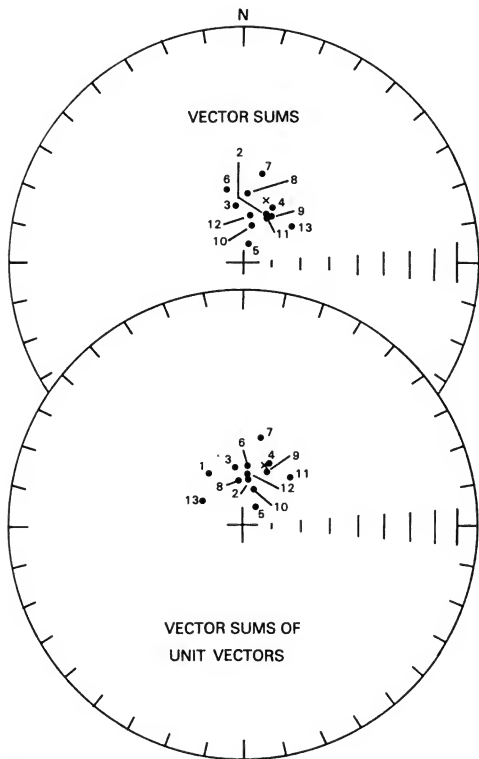


Fig. 10 — Stereograms showing the directions of magnetisation of the vector sums (Vector 1, Table 3), and of the vector sums of unit vectors (Vector 2, Table 3), for groups of New Zealand igneous rocks. The numbers indicate the group (see Table 3). An upper hemisphere projection is used. All directions are upward (normal). Note the directions are generally close to that of the Earth's present magnetic field, which is marked by a cross.

TABLE 3: Directions of magnetisation in igneous rocks from New Zealand. Note that the angular differences between the direction of the present field and that of Vector Sum (1), and Vector Sum of Unit Vectors (2), namely θ and λ , are less than 20° for most groups.

| | | | Vector Sum (1) | | | Vector sum of unit vectors (2) | | | | | | |
|----|------------|-------------------------|----------------|------|-----|--------------------------------|------|-----|-----|----------|-----------|----------|
| | | | n | Jn | D | I | Rn | D | I | θ | λ | ω |
| 1 | PHYOLITE | Central Volcanic Region | 29 | 1.27 | 295 | -44 | 0.71 | 328 | -68 | 29 | 48 | 19 |
| 2 | | Canterbury | 22 | 1.04 | 28 | -73 | 0.97 | 9 | -74 | 6 | 7 | 9 |
| 3 | IGNIMBRITE | Central Volcanic Region | 21 | 2.06 | 352 | -70 | 0.98 | 353 | -69 | 1 | 10 | 11 |
| 4 | ANDESITE | Central Volcanic Region | 27 | 9.06 | 28 | -68 | 0.93 | 22 | -66 | 4 | 3 | 1 |
| 5 | | Canterbury | 36 | 3.25 | 19 | -84 | 0.95 | 33 | -82 | 3 | 17 | 15 |
| 6 | TRACHYTE | Otago Peninsula | 13 | 1.20 | 348 | -64 | 0.94 | 5 | -69 | 9 | 13 | 5 |
| 7 | BASALT | Central Volcanic Region | 13 | 5.01 | 11 | -58 | 0.95 | 12 | -58 | 1 | 10 | 10 |
| 8 | | Banks Peninsula | 10 | 1.18 | 4 | -66 | 0.69 | 354 | -74 | 10 | 7 | 11 |
| 9 | | Chatham Islands (A) | 23 | 7.12 | 31 | -71 | 0.77 | 23 | -69 | 4 | 6 | 3 |
| 10 | | (B) | 84 | 8.44 | 13 | -77 | 0.90 | 19 | -77 | 2 | 10 | 11 |
| 11 | | Otago Peninsula | 82 | 1.43 | 28 | -74 | 0.52 | 44 | -66 | 10 | 7 | 10 |
| 12 | | East Cape | 18 | 3.74 | 8 | -73 | 0.96 | 8 | -72 | 1 | 8 | 7 |
| 13 | PERIDOTITE | Dun Mtn, Blue Mtn | 26 | 2.02 | 53 | -68 | 0.48 | 302 | -73 | 30 | 12 | 25 |

n = number of specimens

Vector (1): Jn = (Intensity of the Vector Sum Intensity of n vectors)/n

Vector (2): Rn = (Vector sum of n unit vectors)/n

D = Declination (deg.); I = inclination (deg., negative upwards)

θ = Angle (deg.) between Vectors 1 and 2, in the plane through the vectors

λ = Angle (deg.) between Vector 1 and the present field direction ($D = 20^\circ E$, $I = -67^\circ$)

ω = Angle (deg.) between Vector 2 and the present field direction

direction of the vector sum assuming $J = 1$, are generally close to the direction of the earth's present magnetic field.

The cause of the log-normal distribution is not certain but may be related to the distribution of grain size.

The best estimate of J , to use in interpreting magnetic anomalies over an igneous body in New Zealand is $e^{\mu + \frac{1}{2}\sigma^2}$, where μ and σ are the mean and standard deviation of $\ln J$ of specimens from the body. For most of the bodies studied, the direction of magnetisation can be taken as that of the present field (approx. $D = 20^\circ E$, $I = -67^\circ$).

ACKNOWLEDGEMENTS

We thank T. Hatherton and W. I. Reilly for criticism of the manuscript.

APPENDIX 1: NOTATION AND UNITS

No standard notation has been adopted in magnetic studies; in this paper the notation used by Irving (1964) is generally used. Vectors are indicated by bold face type; scalar quantities are indicated by standard face (roman) type.

- J** = intensity of magnetisation (A/m)
- D** = declination (deg., East of geographic north)
- I** = inclination (deg., -ve upwards)
- H** = magnetic field strength (A/m)

Components of magnetisation are indicated by subscripts: i for induced and r for remanent magnetisation. S.I. units are used; conversion factors between S.I. and c.g.s. units are given by Reilly (1972). The abbreviation \ln is used for logarithms to the base e (\log_e).

APPENDIX 2: SAMPLING STATISTICS FOR A LOG-NORMAL DISTRIBUTION

Definition

X has a log-normal distribution if $Y = \ln X$ has the probability density function

$$f_Y(y) = \frac{1}{\sqrt{2\pi}\sigma} e^{-(y-\mu)^2/2\sigma^2}$$

where μ and σ are the mean and standard deviation of Y .

Thus the probability that $Y < y_0$ is given by

$$\text{Prob}(Y \leq y_0) = \int_{-\infty}^{y_0} \frac{1}{\sqrt{2\pi}\sigma} e^{-(y-\mu)^2/2\sigma^2} dy$$

The probability density function for X is given by

$$\begin{aligned} f_X(x) &= \frac{d}{dx} \text{Prob}(X \leq x), & x > 0 \\ &= \frac{d}{dx} \text{Prob}(\ln X \leq \ln x) \\ &= \frac{d}{dx} \text{Prob}(Y \leq \ln x) \\ &= \frac{d}{dx} \int_{-\infty}^{\ln x} \frac{1}{\sqrt{2\pi}\sigma} e^{-(y-\mu)^2/2\sigma^2} dy \end{aligned}$$

i.e.

$$f_X(x) = \frac{1}{\sqrt{2\pi}\sigma x} e^{-(\ln x - \mu)^2/2\sigma^2}, \text{ where } x > 0 \quad (\text{A1})$$

Mean and standard deviation of X (Throughout the following, a bar over a quantity denotes mean value.)

The mean value of X , \bar{X} , is by definition

$$\begin{aligned} \int_0^\infty x f_X(x) dx \\ = \int_0^\infty \frac{1}{\sqrt{2\pi}\sigma} e^{-(\ln x - \mu)^2/2\sigma^2} dx \end{aligned}$$

Substituting $x = e^\theta$,

$$\begin{aligned} \bar{X} &= \int_{-\infty}^\infty \frac{1}{\sqrt{2\pi}\sigma} e^{-(\theta - \mu)^2/2\sigma^2} e^\theta d\theta \\ &= e^{\mu + \sigma^2/2} \int_{-\infty}^\infty \frac{1}{\sqrt{2\pi}\sigma} e^{-(\theta - (\mu + \sigma^2))^2/2\sigma^2} d\theta \end{aligned}$$

i.e.

$$\bar{X} = e^{\mu + \sigma^2/2} \quad (\text{A2})$$

The variance of X (the square of the standard deviation, S , of X), $\text{var}(X)$ is by definition

$$\int_0^\infty x^2 f_X(x) dx - \bar{X}^2$$

making the same substitution, $x = e^\theta$:

$$\begin{aligned}\text{var}(X) &= \int_{-\infty}^{\infty} \frac{1}{\sqrt{2\pi}\sigma} e^{-(\theta-\mu)^{1/2}/2\sigma^2} e^{2\theta} d\theta - \bar{X}^2 \\ &= e^{2\mu+2\sigma^2} - e^{2\mu+\sigma^2} \\ &= e^{2\mu+\sigma^2} \{e^{\sigma^2} - 1\}\end{aligned}$$

so that

$$S = \sqrt{\text{var}(X)} = e^{\mu+\sigma^2/2} \{e^{\sigma^2} - 1\}^{1/2}, \quad (\text{A3})$$

From a sample of values of X , we estimate $\hat{\mu}$ and $\hat{\sigma}$, denoted μ and σ , by the maximum likelihood estimates

$$\hat{\mu} = \left(\sum_{i=1}^n \ln X_i \right) / n \quad (\text{A4})$$

$$\hat{\sigma}^2 = \left\{ \sum_{i=1}^n (\ln X_i)^2 - n\hat{\mu}^2 \right\} / (n-1)$$

$\hat{\mu}$ and $\hat{\sigma}^2$ are unbiased estimates of μ and σ ; by the Gauss-Markov theorem $(n-1)\hat{\sigma}^2/\sigma^2$ is a χ^2 random variable with $n-1$ degrees of freedom and is statistically independent of $\hat{\mu}$.

Comparison of $e^{\hat{\mu}+\hat{\sigma}^2/2}$ and $\Sigma X_i/n$

To compare these two estimates of the mean of X we need to calculate the mean and standard deviation of each statistic.

Since $e^{\hat{\mu}+\hat{\sigma}^2/2} = e^{\hat{\mu}} e^{\hat{\sigma}^2/2}$ and $\hat{\mu}$ and $\hat{\sigma}^2$ are independent, the mean of $e^{\hat{\mu}+\hat{\sigma}^2/2}$ is the product of the means of $e^{\hat{\mu}}$ and $e^{\hat{\sigma}^2/2}$.

Mean of $e^{\hat{\mu}}$

$$e^{\hat{\mu}} = \left(\prod_{i=1}^n X_i \right)^{1/n} \quad (\text{II denotes product})$$

$$\begin{aligned}\overline{e^{\hat{\mu}}} &= \int_0^\infty \dots \int_0^\infty \left(\prod_{i=1}^n X_i \right)^{1/n} \frac{1}{n} \prod_{i=1}^n \left(\frac{1}{\sqrt{2\pi}\sigma X_i} e^{-(\ln X_i - \mu)^{1/2}/2\sigma^2} \right) dx_1 \dots dx_n \\ &= \left(\int_0^\infty \frac{1}{\sqrt{2\pi}\sigma} \frac{x^{1/n}}{x} e^{-(\ln x - \mu)^{1/2}/2\sigma^2} dx \right)^n\end{aligned}$$

Substituting $\theta = x^{1/n}$ yields the result:

$$\overline{e^{\hat{\mu}}} = e^{\mu+\sigma^2/2n} \quad (\text{A5})$$

which converges to e^μ as $n \rightarrow \infty$.

Mean of $e^{\hat{\delta}/2}$

Since $(n-1)\hat{\sigma}^2/\sigma^2$ is a χ^2 random variable with $n-1$ degrees of freedom, we can write

$$(n-1)\hat{\sigma}^2/\sigma^2 = \sum_{j=1}^{n-1} Z_j^2$$

when Z_j are independent normal random variables with zero mean and unit standard deviation.

$$\begin{aligned} \text{Then } \overline{e^{\hat{\delta}/2}} &= \int_{-\infty}^{\infty} \dots \int_{-\infty}^{\infty} e^{\sigma^{1/2}/2(n-1)} \sum_{j=1}^{n-1} Z_j^2 \prod_{j=1}^{n-1} \frac{1}{\sqrt{2\pi}} e^{-Z_j^2/2} dZ_1 \dots dZ_{n-1} \\ &= \left(\int_{-\infty}^{\infty} e^{\sigma^{1/2}/2(n-1)z^2} \frac{1}{\sqrt{2\pi}} e^{-z^2/2} dz \right)^{n-1} \\ &= \left(\int_{-\infty}^{\infty} \frac{1}{\sqrt{2\pi}} e^{-z^2/2} \left(\frac{n-1-\sigma^2}{n-1} \right) dz \right)^{n-1} \\ &= \left(\frac{n-1}{n-1-\sigma^2} \right)^{\frac{n-1}{2}} \end{aligned} \quad (\text{A6})$$

which converges to $e^{\sigma^{1/2}}$ as $n \rightarrow \infty$.

Combining (A5) and (A6) yields

$$e^{\hat{\mu} + \hat{\delta}/2} = e^{\mu + \sigma^{1/2}n} \left(\frac{n-1}{n-1-\sigma^2} \right)^{\frac{n-1}{2}} \quad (\text{A7})$$

which converges to $e^{\mu + \sigma^{1/2}}$ as $n \rightarrow \infty$. However, for finite samples, $e^{\hat{\mu} + \hat{\delta}/2}$ will be a biased estimate.

Variance of $e^{\hat{\mu} + \hat{\delta}/2}$

$$\text{var}(e^{\hat{\mu} + \hat{\delta}/2}) = \overline{e^{2\hat{\mu} + \hat{\delta}}} - (\overline{e^{\hat{\mu} + \hat{\delta}/2}})^2$$

by similar calculations to those which yielded (A5) and (A6)

$$\begin{aligned} \overline{e^{2\hat{\mu} + \hat{\delta}}} &= e^{2\mu + 2\sigma^{1/2}n} \left(\frac{n-1}{n-1-2\sigma^2} \right)^{\frac{n-1}{2}} \\ \text{So } \text{var}(e^{\hat{\mu} + \hat{\delta}/2}) &= e^{2\mu + \sigma^{1/2}n} \left\{ e^{\sigma^{1/2}n} \left(\frac{n-1}{n-1-2\sigma^2} \right)^{\frac{n-1}{2}} - \left(\frac{n-1}{n-1-\sigma^2} \right)^{n-1} \right\} \end{aligned} \quad (\text{A8})$$

Mean and variance of $\sum X_j/n$

$\sum_{j=1}^n X_j/n$ is an unbiased estimate of \bar{X} . We need only calculate

$$\text{var}\left(\sum_{j=1}^n X_j/n\right) = \left(\sum_{j=1}^n X_j/n\right)^2 - \bar{X}^2$$

$$\begin{aligned}
&= \int_0^\infty \dots \int_0^\infty \sum_j X_j^2 + \sum_{i \neq k} \sum_{X_i} X_i \cdot 1/n^2 \prod_j \frac{1}{\sqrt{2\pi\sigma X_j}} e^{-(\ln X_j - \mu)^2/2\sigma^2} dX_1 \dots dX_n - \bar{X}^2 \\
&= \frac{1}{n} e^{2\mu+2\sigma^2} + \frac{n-1}{n} e^{2\mu+\sigma^2} - e^{2\mu+\sigma^2}
\end{aligned}$$

i.e.

$$\begin{aligned}
\text{var}\left(\sum_{j=1}^n X_j/n\right) &= \frac{1}{n} e^{2\mu+\sigma^2} (e^{\sigma^2} - 1) \\
&= S^2/n
\end{aligned} \tag{A9}$$

REFERENCES

- Aitchison, J., and J. A. C. Brown 1957. The log-normal distribution. Cambridge University Press, Cambridge.
- Coombes, D. S., and T. Hatherton 1959. Paleomagnetic studies of Cenozoic volcanic rocks in New Zealand. *Nature* 184: 883-884.
- Cox, A. 1971. Remanent magnetisation and susceptibility of Late Cenozoic rocks from New Zealand. *N.Z. Journal of Geology and Geophysics* 14: 192-207.
- Evans, A. Ll. 1970. Geomagnetic polarity reversals in a Late Tertiary lava sequence from the Akaroa Volcano, New Zealand. *Geophysical Journal of the Royal Astronomical Society* 21: 163-183.
- Grindley, G. W.; C. J. D. Adams; J. T. Lumb; W. A. Watters 1977. Paleomagnetism, K-Ar dating and tectonic interpretation of Upper Cretaceous and Cenozoic volcanic rocks of the Chatham Islands, New Zealand. *N.Z. Journal of Geology and Geophysics* 20: 425-427.
- Hunt, T. M. 1974. Rock magnetism in the alpine-peridotite body at Dun Mountain, New Zealand. *Journal of the Royal Society of New Zealand* 4: 433-445.
- Hunt, T. M., and T. C. Mumme 1977. Laboratory investigation of remanent magnetisation in some rocks from New Zealand and Antarctica. *Geophysics Division, DSIR, Report 125*.
- Irving, E., L. Molyneux, S. K. Runcorn 1966. The analysis of remanent intensities and susceptibilities of rocks. *Geophysical Journal of the Royal Astronomical Society* 10: 451-464.
- Koenigsberger, J. G. 1939. Natural residual magnetism of eruptive rocks. *Terrestrial Magnetism and Atmospheric Electricity* 43: 119-130, 299-320.
- McElhinny, M. W. 1973. *Paleomagnetism and Plate Tectonics*. Cambridge University Press: Cambridge.
- Nagata, T. 1961. *Rock Magnetism*. Maruzen Co. Ltd.: Tokyo.
- Oliver, P. J.; T. C. Mumme; G. W. Grindley; P. Vella 1979. Paleomagnetism of the Upper Cretaceous Mount Somers Volcanics, Canterbury, New Zealand. *N.Z. Journal of Geology and Geophysics* 22: 199-212.
- Reilly, W. I. 1972. Use of the International System of Units (SI) in geophysical publications. *N.Z. Journal of Geology and Geophysics* 15: 148-156.
- Risk, G. F.; T. C. Mumme; T. Hatherton 1977. An unusual magnetic schist near the Paradise Scheelite Lode, Glenorchy, New Zealand. *Journal of the Royal Society of New Zealand* 7: 395-403.
- Stacey, F. D. 1963. Physical theory of rock magnetism. *Advances in Physics* 12: 45-133.
- Stacey, F. D., and S. K. Banerjee 1974. The physical principles of rock magnetism. Elsevier, London.
- Wellman, H. W. 1973. The Stokes Magnetic Anomaly. *Geological Magazine* 110: 419-429.
- Whiteford, C. M., and J. T. Lumb 1975. A catalogue of physical properties of rocks Volume 3: Listing by rock type. *Geophysics Division, DSIR, Report 107*.

***Anuropus novaezealandiae*, a new species of Anuropodidae (Isopoda: Flabellifera) from New Zealand**

K. P. Jansen*

Anuropus novaezealandiae n.sp. is described from a single specimen from the regurgitation of a grey-faced petrel (*Pterodroma macroptera gouldi*) on Whale Island, New Zealand. Specific variation and distribution in *Anuropus* are discussed, and a key to the species is given.

INTRODUCTION

The genus *Anuropus* was established by Beddard (1886a) for an isopod from the western Pacific 'Among the deep sea species the most remarkable and interesting ... described below under the name of *Anuropus branchiatus*'. He considered the genus to belong to the flabelliferan family Cymothoidae (1886a, 1886b), but Stebbing (1893) made it the type of a new family Anuropidae, and Hansen (1903) agreed. *Anuropus branchiatus* is still represented by the single specimen taken from 1070 fm (1958 m) off New Guinea during the voyage of HMS *Challenger*. It was the only known representative of the genus until Hale (1952) described *Anuropus antarcticus* '... taken in the Pack Ice from the stomach of a Snow Petrel ...'. This, like *A. branchiatus*, was based on a single specimen, which was however 'not in good condition'. From 1951 to 1954, five specimens of a further species, *Anuropus bathypelagicus*, were taken by the Scripps Institution of Oceanography in depths from the surface to 1600 fm (2928 m) in the eastern Pacific (Menzies and Dow, 1958). *Anuropus pacificus* was described by Lincoln and Jones (1973) from three specimens found in the regurgitation of the Waved Albatross, *Diomedea irrorata*, from Hood Island, Galapagos. Schultz (1977) described another species, *Anuropus australis*, taken in 'Antarctic waters from about 20° to 140° W ... between 851 and 2502 m at least 210 m above the bottom.' From the stomach of an albatross, *Diomedea chlororhynchus*, breeding on Nightingale Island in the Tristan da Cunha Archipelago, a somewhat damaged specimen was named *Anuropus aeronautus* by Sivertsen and Holthuis (1980). More recently, in a study of the food of grey-faced petrels (*Pterodroma macroptera gouldi*) on Whale Island, New Zealand, Imber (1973) recovered a variety of crustaceans from regurgitations, of which one damaged isopod was identified as *Anuropus*. Although it differs considerably from *Anuropus branchiatus* and *A. bathypelagicus*, it resembles the remaining species but is separated by details of the head, coxal plates and pleon and is here described as a new species, *Anuropus novaezealandiae*.

Family Anuropodidae Stebbing

Anuropidae, Stebbing, 1893:345; Menzies and Dow, 1958: 2; Gordon, 1958: 12; Schultz, 1969: 137; Schultz, 1977: 79; Kussakin, 1979: 220.

Anuropinae, Hansen, 1903: 19; Nierstrasz, 1931: 162; Hale, 1952: 29; Gordon, 1958: 12.

Anuropodidae, Sivertsen and Holthuis, 1980: 28.

Type genus: *Anuropus* Beddard.

The name of the genus given by Beddard is unfortunate since it implies the absence of uropods which are in fact present but concealed in dorsal view by the pleotelson. Although the uropodal rami are, like the pleopods, unsclerotised, the peduncles, which

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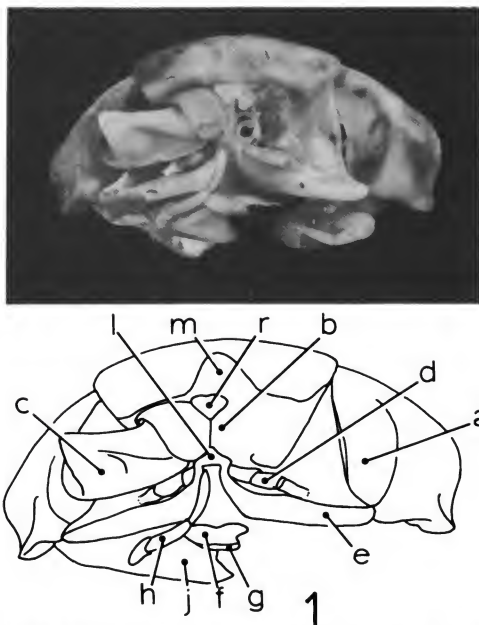


Fig. 1 — *Anuropus novaeseelandiae* n.sp., holotype male. (above) Anterior view of cephalon and pereonite 1. (below) a, transverse groove, extension from cephalon on to pereonite 1; b, position of insertion of left antenna 1; c, right antenna 1; d, remnant of left antenna 2; e, left transverse wall; f, clypeus; g, labrum; h, mandibular palp; j, mandible; l, frontal plate (apex damaged); m, medial concavity; r, r, anterior and dorsal views of rostrum.

are small, do not differ from the typical flabelliferan form and can be moved laterally to form the caudal fan proper to flabelliferans.

The compound name *Anuropus* refers to the apparent lack of uropods, or uropoda, and therefore, in correspondence with Dr L. B. Holthuis and Mr R. V. Melville of the International Commission for Zoological Nomenclature, it was decided that the proper form of the family name is Anuropodidae as introduced by Sivertsen and Holthuis (1980).

Genus *Anuropus* Beddard

Anuropus, Beddard, 1886a: 152-154; Beddard, 1886b: 112-114; Stebbing, 1893: 345; Hansen, 1903: 19; Nierstrasz, 1931: 162; Hale, 1952: 29; Menzies and Dow, 1958: 1-2; Gordon, 1958: 7-13; Schultz, 1969: 138; Lincoln and Jones, 1973: 79; Schultz, 1977: 80; Kussakin, 1979: 220.

Type species: *Anuropus branchiatus* Beddard, by monotypy.

KEY TO THE SPECIES OF *Anuropus*

1. Pleon width increasing from pleonite 1 to rounded flattened pleotelson 2
 — Pleon sides nearly parallel, pleotelson tongue-shaped 3
2. Coxal plates rounded *A. branchiatus*
 — Coxal plates pointed *A. bathypelagicus*
3. Head anterior margin nearly straight, centre slightly concave 4
 — Head anterior margin centre deeply concave 5
4. Pleotelson wider than long *A. australis*
 — Pleotelson longer than wide *A. antarcticus*
5. Frontal plate base wider than centre part of transverse wall *A. novaezealandiae*
 — Frontal plate nowhere wider than centre part of transverse wall 6
6. Pereonite 1 antero- and postero-lateral angles produced *A. aeronautus*
 — Pereonite 1 angles not produced *A. pacificus*

Anuropus novaezealandiae n.sp. (Figs. 1-11)

Diagnosis: *Anuropus* with anterior margin of head deeply excavated; frontal plate triangular, base wider than outer sides of anterior part of transverse wall; pereonite 1 outer margin slightly concave, without processes; pleon, first five segments of equal width, pleotelson with sides folded down and concave, lateral margins curving smoothly to apex.

Note: In this paper I follow Hansen's (1903) and Gordon's (1958) naming of head and mouth parts. Neither Menzies and Dow (1958) nor Sivertsen and Holthuis (1980) mention the frontal plate, but both refer to the rostrum not meeting the clypeus, neither of which is labelled in the figures of either paper. Hansen does not mention the rostrum in the text but describes the frontal plate, the 'upper part' of which is constituted by the upturn of the middle of the transverse wall. Both rostrum and frontal plate are shown but not labelled in his Figure 1. He then refers to both clypeus, '(f)', and labrum '(g in Pl. 4 figs. 1 & 2)'. Hale (1952) refers to the rostrum (figured, unlabelled) as a 'median subtriangular process'; he continues 'the V-shaped transverse wall (damaged at anterior end) is deep and narrow' without referring to the frontal plate, and then mentions the clypeus and labrum as separate parts. Lincoln and Jones (1973) refer specifically only to '... a small vertical triangular 'rostrum' ...', shown but not labelled in Figure 2(b).

Material examined: Holotype male, New Zealand Oceanographic Institute number H354.

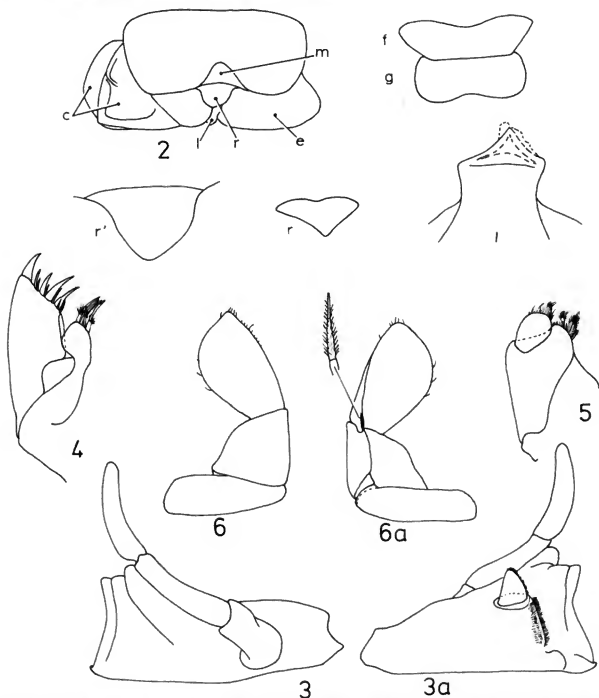
Description: Dimensions are approximate as the specimen was in several pieces when first examined: length about 40 mm. width at pereonite 3 about 10 mm.

Head: width two and one half times length, one half width of pereonite 1. Eyeless. Dorsal surface slightly convex. Anterior margin with deep medial excavation. Lateral margins convex. Rostrum, broad based triangle with longitudinal medial groove, rounded apex curved toward but not meeting frontal plate. Frontal plate (apex damaged) triangular, base wider than medial part of transverse wall. Transverse wall deep, narrow, lateral parts forming very obtuse angle. Clypeus wider than long, laterally convex, medially concave. Labrum narrower than clypeus, wider than long, flat, lateral margins convex, posterior margin concave medially.

Antenna 1: two articles; article 1 cup-shaped, open ventrally; article 2, flattened setiferous base curving posteriorly around head, triangular ridges rising toward and meeting in high peak at antero-lateral angle.

Antenna 2: remnants only.

Mandible: palp of three articles; incisor process strongly sclerotised with medial concavity and small posterior tooth; molar process curved truncate triangle, medial margin with spines, based joined by suture to body of mandible; spine row (Gordon, 1958), or lacinia mobilis (Hansen, 1903), multiple rows of spines, contiguous to base of molar process. Maxilla 1: exopodite with 10 strong spines, five large and five small; endopodite with five long setiferous processes. Maxilla 2: distal article (3) with 11 mostly non-setiferous spines around apex, article 2 with lobe bearing nine mostly setiferous

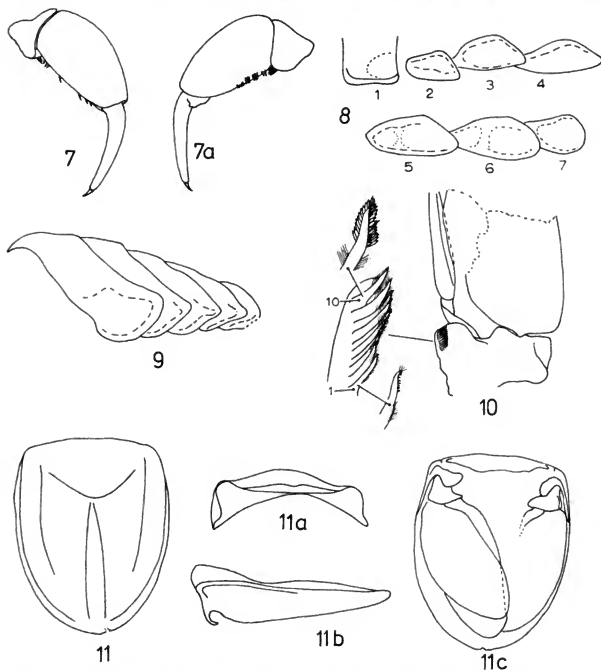


Figs. 2-6—*Anuropus novaezealandiae* n.sp., holotype male 2, dorsal view of cephalon. 3, 3a, ventral and dorsal views of mandible. 4, maxilla 1. 5, maxilla 2. 86, 6a, ventral and dorsal views of maxilliped, with enlargement of seta on article 2.

spines. Maxilliped: basal article twice as wide as long, article 2 about as wide as long, bi-articulate setiferous spine at antero-medial angle; palp entire, large, about one and one third times length of article 2, inner margin slightly, outer margin deeply convex, both with well separated single setae, apex rounded with a cluster of five setae.

Pereon (damaged, pereonites separated): pereonites 1-7 of about equal length; pereonite 1 lateral angles rounded, without processes, margins slightly concave. Coxal plates 2-6 progressively larger posteriorly, 7 about equal in size to 2; 2 and 3 irregularly rhomboidal, 4, 5 and 6 irregularly ovate, 7 oval.

Pereopod 1: chelate, stout, slender dactylus of same length as propodus; propodus expanded, outer margin convex, inner margin nearly straight, grooved, sparsely setiferous and spinose. Pereopods 2-7 incomplete, more slender and longer than 1.



Figs. 7-11 — *Anuropus novaezealandiae* n.sp., holotype male. 7, 7a, ventral and dorsal views of distal articles of pereopod 1. 8, left lateral margin of pereonite 1, coxal plates 2-7. 9, lateral view of pleonites 1-5. 10, remnant of pleopod 2 with male appendix, enlargements of coupling hooks. 11, 11a-b, dorsal, posterior and left lateral views of pleotelson. 11c, ventral view of pleotelson with right uropod in situ (left uropod damaged).

Pleon: five pleonites and pleotelson. Pleonites of equal width, narrower than pereonite 7, laterally curved posteriorly. Pleotelson sides folded down abruptly and concave, forming ridges, posterior margin flat and rounded (apex damaged, obscuring presence or absence of apical point); dorsal surface anterior raised, posterior depressed with obscure medial longitudinal groove, slightly wider posteriorly and with sides slightly curved.

Pleopods: 1 missing, 2-5 damaged; 2-4, peduncles with 10 spinose and setiferous 1- and 2-articulate coupling hooks; 2, basal remnant of male appendix stout, cross section triangular, tapering distally.

Uropods: peduncle inserted ventro-laterally, small, inner process short, movable laterally; rami nearly reaching end of pleotelson, outer slightly wider and shorter than inner, both approximately oblong-ovate.

Distribution and variation in species of *Anuropus*

As indicated in the key the species of *Anuropus* are divided into two groups by the form of the pleon, which either increases in width posteriorly or has roughly parallel sides. In the first group, *A. branchiatus* and *A. bathypelagicus*, all specimens were immature or female and shared a different character with *A. australis* which, alone in the second group, is represented by immature or female specimens. The outline of the distal article of antenna 1 in these species is smooth and curved, contrasting markedly with the strongly sculptured form of the article in *A. pacificus*, *A. aeronautus* and *A. novaezealandiae*, known only from male specimens (antenna 1 was missing from the male specimen of *A. antarcticus*). Thus although the differences among the latter three or four species are unlikely to arise from growth or sexual differentiation, it is possible that *A. australis* may be the female of one or the other. On geographical grounds, *A. aeronautus* or *A. antarcticus* seem the most likely candidates.

Each species is represented by one or a few specimens taken from distinct water masses or from birds presumably feeding in distinct water masses: *A. branchiatus* from 2° 33' S in the western Pacific near New Guinea and *A. bathypelagicus* from 30° to 41° N in the northeastern Pacific; *A. antarcticus* from a snow petrel (*Pagodroma nivea*) at 66° 23' S, 73° 16' E in antarctic water south of the Indian Ocean, *A. pacificus* from a breeding Waved Albatross (*Diomedea irrorata*) on Hood Island in the Galapagos in the eastern Pacific; *A. australis* from antarctic waters south of the Atlantic and Pacific at about 61° S from 20° to 140° W, *A. aeronautus* from a breeding albatross (*Diomedea chlororhynchus*) in the southern Atlantic and *A. novaezealandiae* from a breeding or fledgling grey-faced petrel (*Pterodroma macroptera gouldi*) on Whale Island, New Zealand, in the southern Pacific.

Anuropus branchiatus was dredged in 1070 fm (1958 m); *A. bathypelagicus* were taken by 'net hauls at midwater depths', the 'depth sampled (fm.)' was given in three cases as 500 (914 m), 1170 (2140 m) and 1600 (2926 m), and in two as 0-680 (1244 m) and 0-660 (1207 m); *A. australis* were collected in a mid-water trawl 'between 851 and 2502 m at least 210 m above the bottom.' All specimens of the other four species were taken from the guts of sea birds feeding at or near the surface.

Imber (1973) wrote: 'Since its [*Pterodroma macroptera gouldi*] normal feeding and breeding range lies in the belt of sub-tropical seas, its south-eastward feeding boundary is probably the sub-tropical convergence lying at about 42° S . . .', and further 'All the evidence indicates that *Pterodroma* detects its prey while on the wing and captures it (if alive) probably within 1 m of the sea's surface . . . Thus the conclusion is inevitable, that grey-faced petrels feed at night on the fauna associated with acoustic scattering layers.' Lincoln and Jones (1973) wrote: 'Since the isopods are partly digested it seems likely that they were eaten by fish which form the diet of the albatross . . . strengthened by the presence of *Meinertia gaudichaudii* (Milne-Edwards), a mouth parasite of tunny (Richardson, 1905), in the same regurgitated food samples.'

Sivertsen and Holthuis (1980) refer to a report by Barham and Pickwell (1969) in which it appears that some specimens of *Anuropus* (not identified beyond generic level) live in the umbrella of large mid-water jellyfish. Menzies and Dow (1958) mention the presence of many nematocysts in a yellowish mass in the intestines of *A. bathypelagicus*. This transportation may extend a range otherwise restricted by a possibly limited swimming capacity.

The limited information prohibits any conclusions about intra-specific differences in depth distribution or sexual behaviour but suggests that *Anuropus* is a cosmopolitan genus consisting of species which are epi- and bathypelagic as well as benthonic and which are isolated within distinct masses of water.

ACKNOWLEDGEMENT

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REFERENCES

- Barham, E. G., G. V. Pickwell 1969. The giant isopod *Anuropus*: a scyphozoan symbiont. *Deep-Sea Research* 16: 525-529.

- Beddard, F. E. 1886a. Preliminary notice of the Isopoda collected during the voyage of H.M.S. 'Challenger'. Part III. *Proceedings of the Zoological Society of London*, 1886 1: 97-122.
- 1886b. Report on the Isopoda collected by H.M.S. 'Challenger' during the years 1873-1876. *Challenger Reports, Zoology* 17: 1-175.
- Gordon, I. 1958. Comparison of *Anuropus branchiatus* Beddard and *A. bathypelagicus* Menzies and Dow. *Annals and Magazine of Natural History* 13, 1: 7-13.
- Hale, H. M. 1952. Isopoda, families Cymothoidae and Serolidae. *British Australia New Zealand Antarctic Research Expedition, 1929-1931. Reports B*, 6, 2: 21-36.
- Hansen, H. J. 1903. The deep-sea isopod *Anuropus branchiatus*, Bedd., and some remarks on *Bathynomus giganteus*, A. M.-Edw. *Journal of the Linnean Society of London, Zoology* 29: 12-25.
- Imber, M. J. 1973. The food of grey-faced petrels (*Pterodroma macroptera gouldi* (Hutton)), with special reference to diurnal vertical migration of their prey. *Journal of Animal Ecology* 42: 645-662.
- Kussakin, O. G. 1979. [Marine and brackish water isopod crustaceans of cold and temperate waters of the northern hemisphere, Suborder Flabellifera.] V serii: *Opredeliteli po Faune USSR, izdavaemye Zoologicheskim Institutom AN USSR*, Vyp. 122. L., 'Nauka', 1979. 472c.
- Lincoln, R. J., and M. B. Jones. 1973. A new species of *Anuropus* from the Galapagos region (Isopoda: Flabellifera: Cirolanidae). *Journal of Zoology, London* 170: 79-86.
- Menzies, R. J., and T. Dow. 1958. The largest known bathypelagic isopod, *Anuropus bathypelagicus* n. sp. *Annals and Magazine of Natural History* 13, 1: 1-6.
- Nierstrasz, H. F. 1931. Die Isopoden der Siboga-Expedition. III. Isopoda genuina. II. Flabellifera. *Siboga-Expeditie 19, Monographie* 32c: 123-233.
- Schultz, G. A. 1969. *How to Know the Marine Isopod Crustaceans*. Pictured Key Nature Series. Brown; Dubuque, Iowa.
- 1977. Bathypelagic isopod Crustacea from the Antarctic and southern seas. *Antarctic Research Series* 23(3): 69-128.
- Sivertsen, E., and L. B. Holthuis. 1980. The marine isopod Crustacea of the Tristan da Cunha Archipelago. *Results of the Norwegian Scientific Expedition to Tristan da Cunha, 1937-1938*. Det Kgl. Norske Videnskabers Selskab, Gunneria 35. Pp. 28-35.
- Stebbing, T. R. R. 1893. *A History of Crustacea (Recent Malacostraca)*. International Scientific Series 74. London.

A new interpretation of the geomorphology of Wellington

Richard W. Heine*

The geomorphology of the Wellington Peninsula and the southeastern side of the harbour is examined and re-interpreted. Many benches are identified at levels up to 200 m, and analysis shows a non-random frequency distribution with height. Levels are related to those in the city area and on Mana and Kapiti islands and are widespread, extending at least to the southern end of the Manawatu Plains and the Trentham basin.

The traditional description involving cycles of erosion is rejected, and the benches are ascribed to marine processes. Interpretations involving warping and tilting are also rejected. The landscape is seen as characterised by benching with a well-developed ancient surface at 180-200 m, on which is superimposed an active period of headward furrow development, ascribed to a stress pattern and climatic events involving extreme storm events.

A horizontal stress pattern is identified, and the course of the Karori Stream explained from it. Features in the Wellington Fault line between Cook Strait and the harbour are shown to have a composite origin, and the fault line is shown to be discontinuous. On the evidence available the fault is not considered to be transcurent in this sector. Correlation on altitude of certain levels outside the area is demonstrated which, if valid, allows those levels to be related to New Zealand interglacial stages.

INTRODUCTION

The tract of land lying to the west of the city of Wellington and bordered by Cook Strait (Fig. 1), referred to loosely as Wellington Peninsula, has been the subject of a number of papers (see for example Cotton, 1957, for references) concerned with both description and interpretation of its geomorphology and structure. The traditional interpretation has, I believe, been based on the belief that the form of the landscape is a result of a number of 'cycles of erosion'. The acceptance of this concept to account for variation in the elevations of extended areas must however, limit the number of discrete elevations capable of being explained, because of the very nature of an erosion cycle, i.e. the extended period over which such a cycle takes place. When faced therefore, with too many levels to be accounted for as cycles of erosion (two in this instance), it was necessary to postulate that the area had undergone warping.

The purpose of this paper is to show that the morphology can be interpreted in a manner completely different to previous work, and new data are presented in support of this. It will be argued that correlation of terrace remnants at different elevations shows that not only can an erosional cycle approach not be sustained, but that neither can its corollary that the outer coastal terraces are warped.

By the use of a large number of measurements of elevations spread throughout the area, it will be shown that these have a non-random frequency distribution, and that there are a much larger number of discrete levels in the area than those described to date (see Heine, 1979, regarding the Wellington City area).

The Wellington Fault between the city and Cook Strait is also analysed, as well as enigmatic features of the drainage pattern (northwards drainage of the Silver Stream, zig-zag nature of the Karori Stream), the origin of the Karori-Khandallah "Long Valley" (Cotton, 1912a), and the isolation of the outer coastal terraces.

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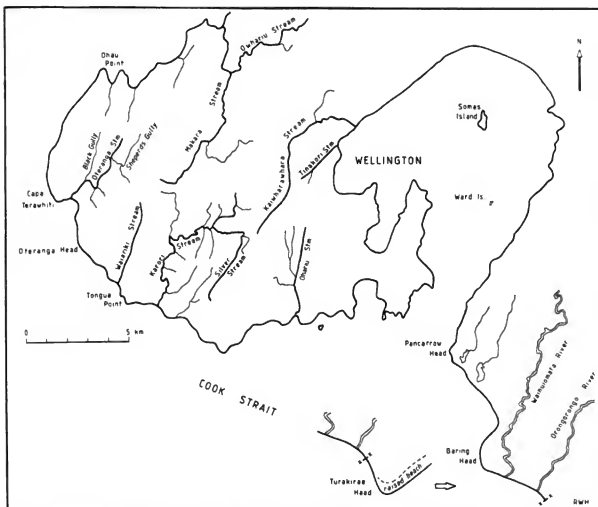


Fig. 1—Locality diagram of the area. Mana Island and the entrance to Porirua Harbour 10 km north of map, Kapiti Island 35 km north of map.

PREVIOUS DESCRIPTIONS

The most prolific writer on the area was the late Sir Charles Cotton, and it is convenient to take his 1957 paper (Cotton, 1957) as a summary of his views. The key element in Cotton's interpretation was recognition of an erosional surface at an elevation of about 300 m, which he regarded as a terminal or summit peneplain, a "plane of reference or key surface, for evaluation of the deformation in later times of the Wellington landscape" (Cotton, 1957: 776). Lower "more or less flat summits" (p. 775) were interpreted as parts of a single surface which had been deformed, and evidence of this warping was seen in the marine terraces of the outer coast, those at Cape Terawhiti being correlated with those at Tongue Point (based partly on work by King (1930)). As a result of this correlation, the coast was described as one of "transverse deformation" (Cotton, 1942, 1952). This required Cotton to reject his own earlier interpretation of the origin of the Makara Valley terraces, where he had proposed an intermediate cycle of erosion called the Tongue Point cycle (Cotton, 1912a). (I subsequently (1974) rejected the correlation of terraces put forward.)

The 1957 paper was also significant in that Cotton abandoned his theory of subsequent relief; i.e., the elongation of the relief was no longer attributed to subsequent stream erosion along the direction of the strike (later extended to subsequent erosion along fault zones with the same direction). Instead he adopted an hypothesis of a tectonic origin of many features of the relief (p. 763). Attention was also drawn (p. 766) to a "number of long and strictly rectilinear valleys; specifically (in the area under discussion here) the valley of the Ohariu Stream.

A possible origin of such features was discussed by Cotton (p. 783) who started by saying that these are "difficult of explanation other than as erosional valleys developed by headward subsequent erosion along fault lines." He then went on however, to argue against this and finally adopted (p. 785) a fault-angle origin, dating from an early phase of the deformation of the terminal peneplain and etched into the present landscape.

In a later paper the landscape was described (Cotton, 1958), apart from the main erosion surface, as being characterised by a fine textured dissection (and re-dissection following cryergic processes), largely consequent on the flanks of the upland remnants (p. 413).

A dominant feature of the area is the Wellington Fault. In 1914 it was recognised as extending southward into the valleys of the Silver and Kaiwharawhara streams because of their alignment, which were accepted as fault-angle in origin (Cotton, 1914). The fault is generally accepted as a dextral transcurrent fault, following the description of shutter ridges near the outer coast (Cotton, 1951), and the Wellington Harbour — Hutt Valley depression interpreted as buckling.

Course of the Karori Stream

An explanation of the course taken by the Karori Stream was proposed by Gage (1940). He considered (p. 405) that originally a branch of the Makara Stream had worked back northwards to capture the headwaters of the "Long Valley", and in turn this had been captured by the Karori, giving rise to the present Karori Stream. The zig-zag of the Karori Stream from Karori down to the junction of its western branch, characterised by short gorge-like reaches connecting lengths of wider valleys, was ascribed to adjustment to structure. This was extended by Cotton (1957: 781), by ascribing at least some of this adjustment to homoclinal shifting.

METHODS

Topographic maps, even on a scale of 1: 15 840, are not sufficiently detailed for geomorphological analysis of the kind used here. The key to new data lies in vertical stereo aerial photographs, not only for visual identification of features but also for the determination of spot heights over a wide area. These were taken directly from NZMS 270 topoplots at a scale of 1: 25 000 and are accurate to within 5 m vertically.

All spot heights mapped in this series were used to create the data base, so that the criteria for site selection were based solely on the ability of the photogrammetry process to detect inflexion or convex stationary points in the landscape. Any attempt at selection would have introduced an unknown bias into what is essentially a statistical approach.

Lination was identified from stereo pairs and transferred directly to topographic plots at 1: 15 840. All topoplots were obtained from the Photogrammetry Branch of the Lands and Survey Department.

DESCRIPTION AND INTERPRETATION

Linations

Apart from the Wellington Fault, and the valley of the Owhiro Stream, no descriptions of other linations have been published for the area covered by Figure 2. This figure maps a pattern of such features (actual lengths and bearings), all seen from aerial photos as narrow rectilinear valleys or furrows, interpreted as an horizontal secondary stress pattern about the Wellington Fault, taken as the primary dislocation. It follows from this, that the origin of these furrows is seen as occurring through headward erosion, rather than by fault-angle movements as proposed by Cotton. A clear example of "secondary" furrow development proceeding out in two diametrically opposite directions from a "primary furrow", is seen at site *B* in Figure 2.

In some cases the furrows are accompanied by fault line facets, line *A* (Fig. 2). When the surface topography is examined the variable strike seen at *C* is consistent with a rectilinear fault plane dipping in reverse to the west.

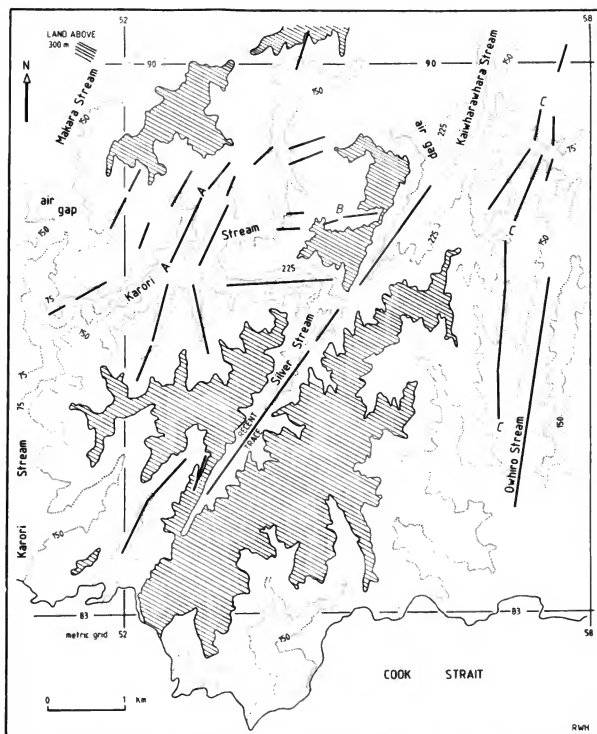


Fig. 2—Map of narrow rectilinear furrows obtained from aerial photographs (bearing and length to scale) interpreted as showing a secondary stress pattern with respect to the Wellington Fault. A-A indicates fault line facets, B a site of headward erosion in two diametrically opposite directions (not mapped), C-C a straight line fault with a reverse dip to the west as judged from its intersection with the surface topography.

Course of the Karori Stream

The identification of a pattern of lineations offers a better explanation of the zig-zag course taken by the Karori Stream than that offered by Gage and Cotton. Cotton's (1957) suggestion of homoclinal shifting is, in my opinion, totally hypothetical in that it has no factual basis for support.

The Wellington Fault

Evidence that the Wellington Fault is dextrally transcurrent over the sector from Wellington city to the coast is based primarily on (a) shutter ridges next to the coast (Cotton, 1951), and (b) trailing streams in the Silver Stream valley (Lensen, 1958). Regarding the latter, the valley of the Silver Stream falls 152 m to the northeast over a distance of 2.8 km, i.e., an average gradient of 1:18, which (coupled with the recognised asymmetry of the valley (Cotton, 1951)) explains the direction taken by the streams entering the valley from the southeastern side. They are merely flowing normal to the contours and are not definitive proof of transcurrent movement.

The suggestion has been made (Lensen, 1958) that shutter ridges are seen in that portion of the Wellington Fault contained in Figure 3. Examination of photographs of this area shows a polycyclic valley system, with headward erosion and furrow development, causing two air gaps (see Fig. 3). The conclusion to be drawn from this is the exact opposite regarding transcurrent movements. It provides no evidence of horizontal movement (Fig. 4), and evidence of vertical movement is seen only in the recent trace.

The "trace" of the Wellington Fault within the Silver Stream valley is seen therefore, to consist of consequent drainage (not on the exact alignment of the recent trace), headward erosion leading to furrow development (but not accompanied by further down cutting of the original Silver Stream), and final vertical movement forming the recent trace.

Frequency distribution of spot heights

Figures 5 and 6 are plots of all spot heights recorded on NZMS 270 topoplots, up to 200 m. These are plotted as a histogram in Figure 7, along with higher elevations to 250 m, with a superimposed three-unit running total. The histogram clearly shows a non-random pattern, with well-developed groups delineating a number of zones. Non-randomness for levels up to 200 m was confirmed by applying a chi-square test to the raw

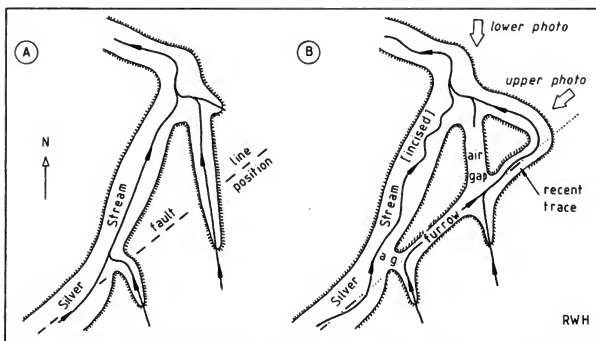


Fig. 3—Section of the Wellington fault line showing composite origin of features. (A) represents topography before headward furrow development (B), which has led to the formation of two air gaps. A recent trace occupies the bottom of the furrow. (See Fig. 4).



Fig. 4—View of Wellington fault (see Fig. 3). *Left* Looking southwest along the fault, with the furrow in the centre foreground, and Silver Stream to the right. *Right* Looking south across the fault, with Silver Stream lower right, the furrow across the photograph left to right and the air gap in the centre. Photos R. W. Heine, 1962.

data, using three unit cells (rippled through three times), with overall trend removed. This test gave a significance level of 0.5%, which is highly non-random.

The reason for testing the elevations only to 200 m, was because the spot heights listed are isolated in space, and hence independent. Above this elevation increasing occurrence of ridges and 'peneplain remnants' leads to a loss of independence between adjacent spot heights i.e., they become replications, so that tabulation of frequencies becomes less certain as a diagnostic tool. Elevations shown in Figure 7 above 200 m are clearly non-random by inspection.

The levels associated with the 188 m and 197 m peaks in the histogram mark a widespread general surface, seen for example as the crest of a ridge west of the Ohariu Valley, and beyond that in Mill Creek Valley. The divide between Ohau Bay and Black Gully (198 m) and the head of Shepherds Gully also fall within this zone, and it is also represented between Khandallah and the harbour, and by Mount Victoria (196 m).

One of the best-defined frequencies is that at 150 m, and the higher terrace at Tongue Point (at 146 m, Cotton, 1942) is associated with this peak. Working from 50 ft contour maps, I pointed out earlier (1974) that the 400 ft (122 m) and 450 ft (137 m) contours delineate a set of benches cut into spurs (as seen in aerial photographs) throughout the general area covered by Figure 5. The '400 ft' feature is identified here with the 119 m peak, and the '450 ft' feature with the 139 m peak. Attention has also been drawn previously (Heine, 1979) to a remarkably level surface at Bell Road (WCC aerial map 9781) at 140 m.

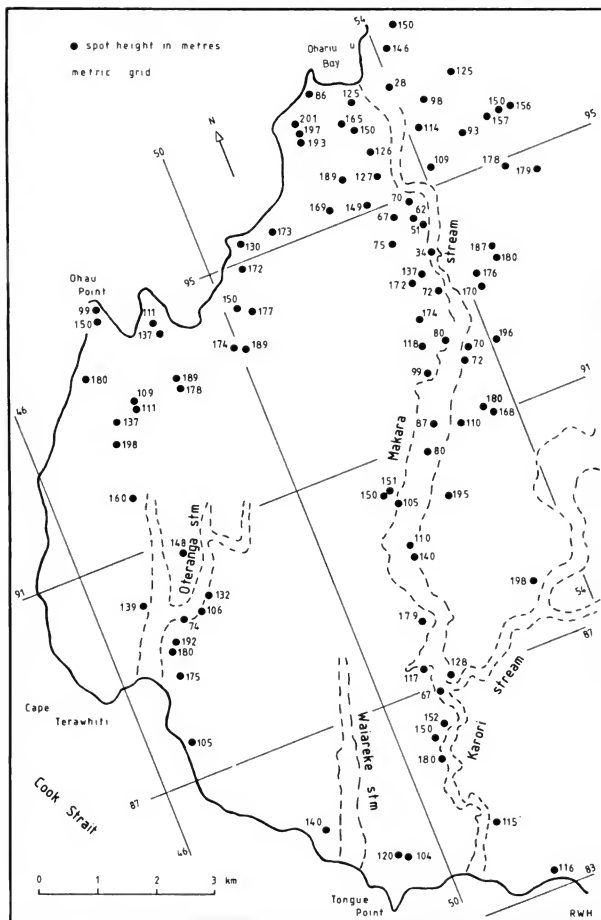


Fig. 5—Map of Wellington Peninsula showing location of spot heights obtained from NZMS 270 topoplots.

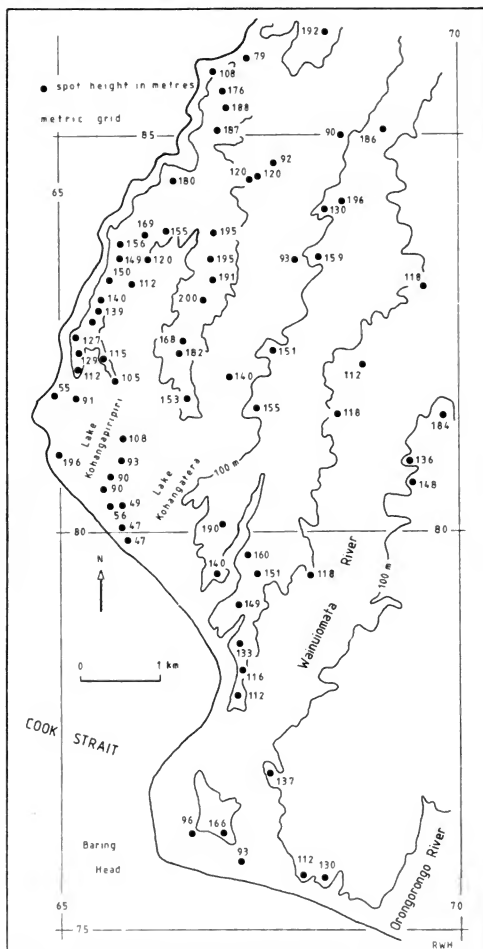


Fig. 6—Map of area east of harbour entrance showing location of spot heights obtained from NZMS 270 topoplots.

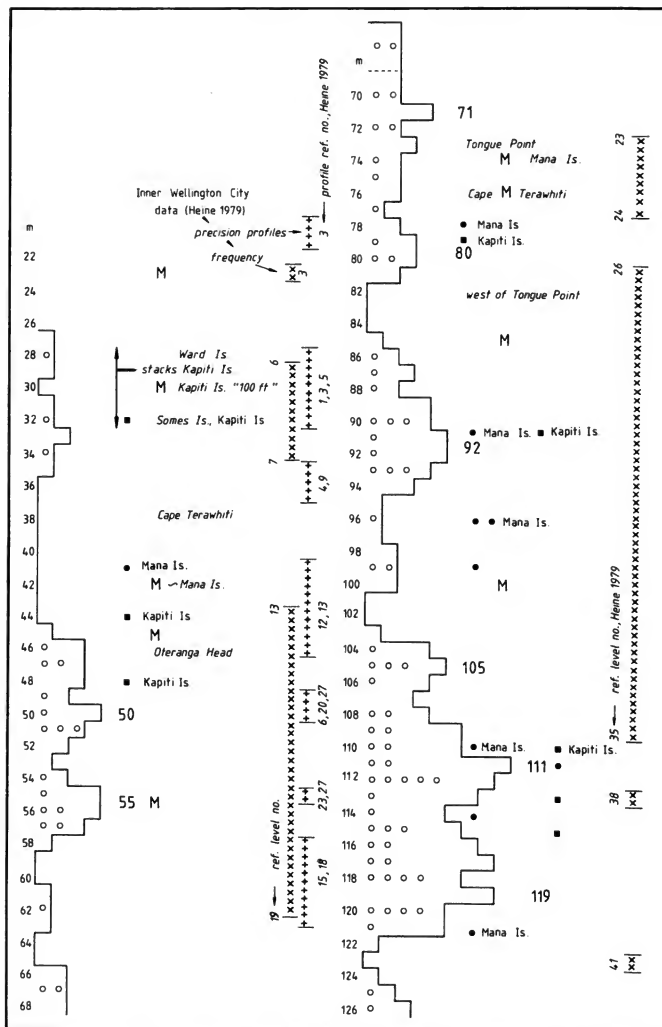
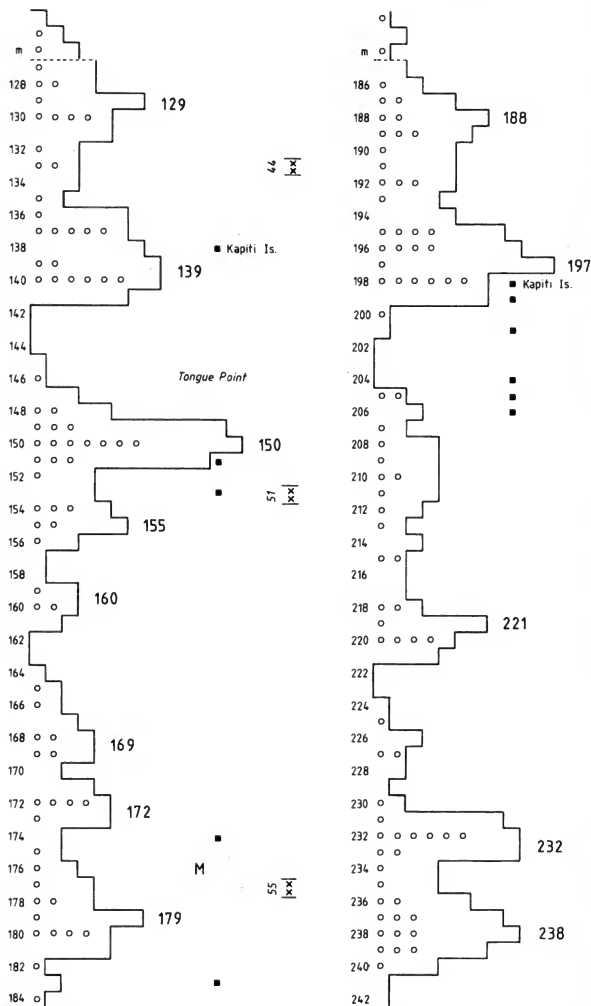


Fig. 7—Histogram of spot heights mapped in Figs. 5 and 6, plus additional values to upright lettering refers to spot elevations outside the area, sloping lettering to large scale features (1979, Table 2).



242 m, with a superimposed three-unit running total. Named items are not part of the data base: within the area of Figs 5 and 6. The letter M refers to major features as documented in Heine

100 m. The small group of levels from 28 to 34 m includes the prominent level terrace at the northern end of Somes Island (32 m), and Taputeranga Island in Island Bay (30 m).

Correlation with inner city levels

Using surveyed elevations, and ultra-detailed contoured maps (contour interval 0.6 m), I documented a large number of levels in the inner city area (Heine, 1979), and tabulated extended surfaces. These 'major' surfaces are marked in Figure 7 by the letter M. Such levels not clearly identified from the data of Figure 7 occur at 42, 45 and 85 m.

In Table 1 of Heine (1979), a histogram was presented of the levels recorded in the inner city, and zones of high frequency are plotted in Figure 7; also shown were precision profiles based on 0.6 m contours, and from these a series of zones can be abstracted. These are plotted in Figure 7 at 21 m, 28 - 32 m, 35 - 35.5 m, 41 - 46 m, 49 - 50 m, 55 m, and 58 - 63.5 m, and annotated with the profile identification numbers. Both the 50 and 55 m peaks are reflected in these profile zones, and profile 27 contains both.

Makara Valley

The divide between Makara Stream and the west branch of the Karori Stream has an elevation of c. 100 m, a level identified in the city area as of major extent. This level represents the highest point of the prominent terrace of the Makara Valley, which continues northwards from the divide with decreasing elevation. Figure 7 shows that the 100 m level represents the highest elevation in a group extending upwards from 85 m. Cotton (1912a) originally correlated this terrace with the lower Tongue Point Terrace, but later (1952) abandoned this on the grounds of inferred warping. A similar reason was used by Gage (1940) to explain the "loss of height" of the terrace surface southward from the divide. This however would require warping on an axis parallel to the coast, whereas Cotton used a warping axis normal to the coast.

A large number of spot heights are shown throughout the valleys of the Makara and Karori streams. They provide no evidence to relate the Makara terrace specifically to the 73 m Tongue Point terrace, nor do they imply warping.

The absence of these outer coastal terraces between Tongue Point and Wellington City (within which the level is identified) was ascribed to warping by Cotton (1952). If this portion of the coast is compared with that between Tongue Point and Cape Terawhiti however, the two are seen to be quite different in their morphology. The latter is a part constructional form of landscape (Heine, 1974), while the coast to the east of Tongue Point contains cliffs cut directly into basement rocks. The absence of the terraces east of Tongue Point to the city is seen therefore as reflecting enhanced marine retrogradation of the coast and not warping.

CORRELATION OF TERRACES OUTSIDE THE AREA

Mana and Kapiti islands

The Mana surface slopes from c. 120 m down to c. 80 m, and in terms of Figure 7, can be seen as made up of two groups of levels, one 85 to 100 m and the other 101 to 122 m. The above limits are identifiable with well-developed features on the main land. The lower limit corresponds to the coastal terraces at 73, 76 and 80 m, while the upper limit corresponds to the "400 ft" features described above. As an alternative to tectonic tilting, the Mana surface can be seen therefore, as part of a continuum extending from 28 m (the seaward edge of Tongue Point and Cape Terawhiti) through to 120 m, with a consistent slope to the southwest. The 42 m 'major' level is also recorded on Mana Island (Williams, 1978).

Some spot elevations are also available on Kapiti Island. A general surface at c. 200 m can be seen and levels corresponding to the 150, 139, 111 and 92 m peaks are identified. A level at 44 m corresponds to the Oteranga Head terrace.

Marine stacks around Kapiti Island (and Mōtingarara Island, off-shore from Kapiti) are commonly 28 - 32 m high, and Fleming and Hutton (1949) have described a c. 30 m bench at Rangatira Point. This level is very well developed within Wellington City (Heine, 1979), and on Somes Island.

Wairarapa coastal terraces

King (1930) describes coastal terraces from Cape Terawhiti eastwards through Cook Strait and up the Wairarapa coast to Castlepoint. Between the Kaiwhata River and Uriti Point he describes a 150 ft (43 m) terrace, up to 3 km in breadth, with a level 8 km inner edge. Behind this he records remnants of a terrace at 220 ft (67 m), together with 14 terrace remnants in the district at 350 ft (107 m). South of the Kaiwhata River, at Flat Point, a terrace is present at 500 ft (152 m), 'descending' northwards to 450 ft (137 m) at the Kaiwhata River, and continuing southward at 500 ft for 13 km. All these terraces are cut into soft Tertiary sandstones and mudstones.

Comparison of these elevations with Figure 7 shows that they can be related to the Wellington data pattern with some consistency. The 150 ft (43 m) terrace relates to the major 42 m level (or 45 m level allowing for known uplift of Wellington), the 350 ft (107 m) to the 111 m peak, and the 500 ft (152 m) terrace to the 150 m level. However the 220 ft (67 m) terrace is not well represented, and it will be suggested in the next section that the c. 72 m Tongue Point and Cape Terawhiti terraces are the likely correlative.

Southwest Auckland and Wanganui terraces

Chappell (1970) describes flights of terraces in Quaternary formations of the southwest Auckland coastal region, which he relates to similar surfaces around South Kaipara Harbour. In a subsequent paper (1975) he extends this correlation to the Wanganui region, identifying the 18-20 m Rapanui terrace with the 21 m Waioneke transgression and the 40-43 m Ngarino terrace with the Shelly Beach transgression of the Kaipara region (Brothers, 1954). He relates the 70 m Brunswick terrace at Wanganui to the 64-67 m Parawai transgression of south Auckland, and the Kaiatea group to the Nihinihi transgression at 107 m. A maximum strand level at c. 155 m is also described, associated with the deposition of the Kaihu formation.

Comparisons with the Wellington data shows that the 18-20 m and 40-42 m terraces are very well identified, and hence these are taken as formed during the last interglacial phase (Suggate's (1965) Oturian Stage). The 70 m Brunswick terrace is associated with the penultimate interglacial (Terangian Stage) and is correlated with the 70 m coastal terrace at Tongue Point. The 64-67 m Parawai transgression of southwest Auckland which is correlated with the 70 m Brunswick terrace by Chappell, can be directly correlated on altitude with Wellington by allowing a c. 6 m uplift in Wellington, and this would accommodate King's 220 ft (67 m) Wairarapa terrace as well.

The 107 m Nihinihi transgression of southwest Auckland marks the peak of the 104-121 m group of levels of which individual levels are well distributed around the Wellington area. If the Kaihu Formation is partly Upper Castlecliffian (Middle Pleistocene) as suggested by Chappell (1975: 150), then the 104-121 m group of levels may be associated with the Waiwhero interglacial (antipenultimate). Chappell (1970) also records a thin pumice silt horizon at 122 m in the Kaihu Formation, as well as two stands of sea level at 46 and 56 m (formation uncertain), and pumice silt horizons at 20, 36.5, and 46 m in the Nihinihi Formation.

DISCUSSION

Analysis of terrace levels

In this paper I have taken a large number of spot heights of features considered 'level' (although not necessarily of large areal extent) and analysed the frequency with which they occur, a method I used earlier (1979) for the Wellington inner city area. This method of analysing the morphology of a landscape is quite different from methods used in previous descriptions, which took large-scale features (e.g. Tongue Point) and typified them with a *single* elevation using an aneroid barometer.

Apart from the variable accuracy of barometric techniques in the absence of a control instrument, the latter method assumes that the variability associated with the readings represents the inherent natural variability of these extended surfaces. However the larger a feature, the less sure can one be that the surface is the result of a *single* event, so that

larger features do not lead to more precise estimates of elevation, and may in fact just reflect the length of time that the sea occupied a restricted range of elevations.

The result of this work is to show a number of well-defined groups of levels, with some fine structure superimposed. Not only are these levels seen on Mana and Kapiti islands, but examination of the relevant NZMS 270 topoplots shows that these levels extend throughout the Wellington area as far north as the Trentham basin, and the southern end of the Manawatu Plains (Paraparaumu). Approximate levels observed include those at 105, 115, 137, 150 and 200 m, and Leamy (1958) has recorded Terraces at 31 m and 50, 54, 57 m in Porirua Harbour.

Groups of levels may describe relatively rapid changes in sea level; Cullen (1967) described a rise in sea level of 50 m over a period of 1700 years in the Foveaux Strait area (from -64 to -14 m).

The possible correlations of certain levels up to 107 m with interglacial periods suggests that higher groups of levels as shown in Figure 7 may be Tertiary features. Brothers (1954) refers to a 550-600 ft (167-183 m) transgression in the Auckland region as possible Pliocene, and Grant-Taylor and Hornibrook (1964) state that Pliocene (Opotian) deposits in the Makara Valley indicate a relative rise of sea level of 152 m.

On a more speculative note, Glenie *et al.* (1968) have related Tertiary sea levels between Australia and New Zealand. They describe (p. 152) "an almost unmodified emerged sedimentary surface" resting on the West Australian shield, "incredibly level" with an inland margin of at least 650 ft (198 m), as Miocene. They also describe a 600 ft (183 m) dissected marine platform cut across Cambrian and Precambrian rocks near Adelaide, which is taken as Pliocene.

Stevens (1973) has suggested a total westward tilt of c. 0.5 m between Turakirae Head and Cape Terawhiti since 1460. This borders on the instrumental resolution used here and is not seen in the data presented in Figure 7, although the precision profiles should be corrected as necessary. Wellman (1967) has described a beach ridge (labelled F by him) east of the Turakirae Head at an elevation of 25 m, and inferred an uplift over 6500 years for this feature. This particular level can be related to the prominent 'major' level at 23 m in the city area, and a caution is made therefore concerning this as evidence for a 25 m uplift.

Analysis of land form and relief

Past analyses saw the landscape as a deformed peneplain with three major faults angle valleys: the corridor isolating the Terawhiti ridge (including Black Gully), and the west and east (Shepherds Gully) branches of the Oteranga Stream plus the Waiariki lineament (seen also as fault angle), the Wellington Fault lineament, and the Owihoro Stream's valley.

Aside from very early deformation of the so-called K surface — which has determined the general form of the landscape above c. 250 m — the present form of the landscape is seen as formed by three distinct phases:

- (1) a period of extensive planation forming a surface at c. 180-200 m (possible also other surfaces higher than this, a "K" surface — but not analysed here);
- (2) a period of rapid headward erosion forming steep narrow, rectilinear gullies and furrows, as mapped here;
- (3) a further period of bench formation at numerous elevations, up to about 180 m.

The features formed in phase 2 are seen as a consequence of two factors, the presence of weak "crush" zones which have allowed headward erosion, and the climate. The furrows are etched from the secondary stress pattern of the Wellington Fault and not from shallow fault angles originating in a "very early phase of the deformation of the K surface . . ." (Cotton 1957: 785). Unless the stress pattern postdates the planation period of phase 1, some other factor must be invoked to explain the triggering of furrow development, as the furrows are cut into the 180-200 m surface, and it seems necessary to postulate a climate change.

It has been suggested (Cotton, 1962) that the origin of fine-textured relief such as that seen in the area under discussion is due to "excessive rainfall intensity", and he quotes in

support of this a 24 hour value of 65 mm. It is suggested here, however, that rather than "intense rainfall" the rainfall causing furrow development is more likely associated with extreme events such as the storm of December 1976. This storm was localized over Wellington and the Hutt Valley, and rainfalls up to 259 mm were recorded over a 12-hour period, causing severe flooding. Such a storm is considered by Tomlinson (1977) to have a return period of greater than 100 years, although the last such storm occurred in December 1939. The origin in both cases was a localised convergence which remained stationary for 12 hours or so. It seems clear that this kind of phenomenon must have a considerable impact on the erosion processes within the area, and in particular the headward development of furrows.

The fact that the Kaiwharawhara Stream has caused headward erosion along the line of the Wellington Fault, and not the Tinakori Stream, is clear evidence that the crush zone does *not* extend northwards through Kelburn and down Tinakori Road as a continuous feature. The crush zone on the corner of Raroa Road and Plunket Street is not on the line of the Wellington Fault and is not evidence of continuity. A similar argument applies to the divide between the Silver Stream and Kaiwharawhara Stream, furrow development by the former being only southwards.

The Wellington Fault

Analysis of the fault-line features in Figure 3, coupled with the furrow evidence above, casts doubt on the continuity of the Wellington Fault from Cook Strait through to the harbour as a *transcurrent* fault. The only evidence in this section for transcurrent movement is that of the shutter ridges near the coast (Cotton, 1951), which imply a horizontal movement of c. 70 m. The evidence should perhaps be regarded with some caution: the ridges cross the fault trace at an angle, so that an apparent horizontal movement of z parallel to the fault trace will result from a vertical movement h , given by $z = h \cot \theta$, where θ is the angle between the ridge and the fault line, and ϕ the westerly reverse dip of the fault plane. Calculation suggests however that to obtain $z = 70$ m, the magnitude required for h would be excessive. Aerial photos also suggest that the surface of the slope is, or has been, covered with transported material, which may affect drainage. (The stream below is deeply incised into loose material.) The question remains however, as to whether this is strike-slip movement as distinct from transcurrent.

Cotton observed (1957: 771), that "the main effects of the Wellington Fault that are apparent in the morphology of the district result from the vertical (dip-slip) component of movement . . .". Even if the downwarping along the western border of the harbour is seen in terms of transcurrent buckling (which is generally accepted), it does not follow that transcurrent movement must be observed from there southwards to the outer coast: one might perhaps expect buckling to indicate a resistance to horizontal movement beyond the buckled zone, i.e., south of the city. The change in strike at Thorndon is not supportive either, to a continuous feature, which is implied in the term *transcurrent*.

The air gap caused by the Kaiwharawhara Stream (see Fig. 2) and described by Cotton (1912b) has an elevation of 198 m, which suggests that the lower basin on the fault line is part of the general surface described above. The northern end of the Silver Stream valley in the second basin has a similar, although less precisely defined, elevation. Both valleys are hence considered to have had their morphology modified by plantation processes (after a hypothetical origin as fault-angles?), with later furrow development and a recent trace giving the lineament structure to each basin.

Correlation of levels with interglacial stages

Suggested correlations given above between certain levels and interglacial stages were: 18-20 m and 40-42 m last interglacial (Oturian), 70 m penultimate interglacial (Terangian), and 107 m for the antipenultimate (Waiwheran). From these c. 2 m may be subtracted in central Wellington for the lowest levels, and perhaps 6 m for the highest.

This leaves a number of intermediate levels unidentified, as seen in precision profiles, and in the data of Figure 7, namely 28-32, 35, 50, 55, and c. 60 m. It is possible that some of these are associated with the Waiwheran stage in view of the pumice silt horizons recorded by Chappell (1970: 140, 143).

Suggestions have been put forward previously (quoted in Stevens, 1957) regarding correlation with overseas interglacial stages, based on elevation. The main difference between these, and this work, is to assign the Tyrrhenian high sea level (via the Brunswick Terrace) to the c. 72 m (Tongue Point, Cape Terawhiti) rather than the older Milazzian.

CONCLUSIONS

The area is characterised by two distinct sets of features, a large number of benches cut at numerous levels up to at least 200 m and seen as of marine origin, and superimposed furrows seen as originating from headward erosion and etched from a stress pattern, both superimposed on a much older and higher peneplain surface. The bench features are widespread and extend to both Mana and Kapiti islands, as well as east of Wellington Harbour. They do not provide evidence of Pleistocene warping or tilting, or vertical movement of the Wellington Fault, other than recent.

Evidence for transcurent movement on the Wellington fault between Cook Strait and Wellington Harbour, other than the possible shutter ridges described by Cotton is examined and rejected. The fault line in this sector is shown to be discontinuous, and its features are of composite origin.

On the basis of altitude, correlation of certain levels is suggested outside the region which, if valid, relate those levels to the New Zealand Oturian, Terangian, and Waiwheran interglacial stages of Suggate (1965).

REFERENCES

- Brothers, R. N. 1954. The relative Pleistocene chronology of the south Kaipara district, New Zealand. *Transactions of the Royal Society of N.Z.* 82: 677-94.
- Chappell, J. 1970. Quaternary geology of the south-west Auckland coastal region. *Transactions of the Royal Society of N.Z. Earth Sciences* 8: 133-53.
- 1975. Upper Quaternary warping and uplift rates in the Bay of Plenty and west coast, North Island, New Zealand. *N.Z. Journal of Geology and Geophysics* 18: 129-55.
- Cotton, C. A. 1912a. Notes on Wellington Physiography. *Transactions of the N.Z. Institute* 44: 245-65.
- 1912b. Recent and sub-recent movements of uplift and of subsidence near Wellington, New Zealand. *The Scottish Geographical Magazine* 28: 306-12.
- 1914. Supplementary notes on Wellington physiography. *Transactions of the N.Z. Institute* 46: 294-98.
- 1942. Shorelines of transverse deformation. *Journal of Geomorphology* 5: 45-58.
- 1951. Fault valleys and shutter ridges at Wellington. *The N.Z. Geographer* 7: 62-8.
- 1952. The Wellington Coast: an essay in coastal classification. *The N.Z. Geographer* 8: 48-62.
- 1957. Tectonic features in a coastal setting at Wellington. *Transactions of the Royal Society of N.Z.* 84: 761-90.
- 1958. Dissection and redissection of the Wellington landscape. *Transactions of the Royal Society of N.Z.* 85: 409-25.
- 1962. The origin of New Zealand feral (fine-textured) relief. *N.Z. Journal of Geology and Geophysics* 5: 269-70.
- Cullen, D. J. 1967. Submarine evidence from New Zealand of a rapid rise in sea level about 11,000 years B.P.. *Palaogeography, Palaeoclimatology, Palaeoecology* 3: 289-98.
- Fleming, C. A., and C. D. Hutton 1949. Notes on the geology of Kapiti Island, Cook Strait, N.Z. *Transactions of the Royal Society of N.Z.* 77: 456-68.
- Gage, M. 1940. The Makara and Karori valleys and their bearing upon the physiographic history of Wellington. *Transactions of the Royal Society of N.Z.* 69: 401-9.
- Glenie, R. G.; J. C. Schofield; W. T. Ward 1968. Tertiary sea levels in Australia and New Zealand. *Palaogeography, Palaeoclimatology, Palaeoecology* 5: 141-163.
- Grant-Taylor, T. L., and N. de B. Hornibrook 1964. The Makara faulted outlier and the age of Cook Strait. *N.Z. Journal of Geology and Geophysics* 7: 299-313.

- Heine, R. W. 1974. Marine terraces at Cape Terawhiti and Tongue Point, Wellington. *Journal of the Royal Society of N.Z.* 4: 485-92.
- 1979. Microanalysis of planation surfaces in Port Nicholson basin (Wellington City), and relationship of tectonic features. *N.Z. Journal of Geology and Geophysics* 22: 379-90.
- King, L. C. 1930. Raised beaches and other features of the south-east coast of the North Island of New Zealand. *Transactions of the N.Z. Institute* 61: 498-523.
- Leamy, M. L. 1958. Pleistocene shorelines at Porirua Harbour, near Wellington, New Zealand. *N.Z. Journal of Geology and Geophysics* 1: 95-102.
- Lensen, G. J. 1958. The Wellington Fault from Cook Strait to Manawatu Gorge. *N.Z. Journal of Geology and Geophysics* 1: 178-96.
- Ongley, M. 1943. Surface trace of the 1855 earthquake. *Transactions of the N.Z. Institute* 73: 84-9.
- Stevens, G. R. 1957. Geomorphology of the Hutt Valley, New Zealand. *N.Z. Journal of Science and Technology* B38: 297-327.
- 1973. Late Holocene marine features adjacent to Port Nicholson, Wellington, New Zealand. *N.Z. Journal of Geology and Geophysics* 16: 455-84.
- Suggate, R. P. 1965. Late Pleistocene geology of the northern part of the South Island, New Zealand. *N.Z. Geological Survey Bulletin* 77.
- Tomlinson, A. I. 1977. The Wellington and Hutt Valley flood of 20th December 1976. *N.Z. Meteorological Service, Technical Information Circular* 154.
- Wellman, H. W. 1967. Tilted marine beach ridges at Cape Turakirae, New Zealand. *Journal of Geosciences, Osaka City University* 10 (1-16): 123-9.
- Williams, D. N. 1978. Pliocene and Quaternary geology of Mana Island. *N.Z. Journal of Geology and Geophysics* 21: 653-6.